Exhibit 1

Climate Change 2007:
Synthesis Report

Synthesis Report

An Assessment of the Intergovernmental Panel on Climate Change

This underlying report, adopted section by section at IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007), represents the formally agreed statement of the IPCC concerning key findings and uncertainties contained in the Working Group contributions to the Fourth Assessment Report.

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Introduction

Introduction

This Synthesis Report is based on the assessment carried out by the three Working Groups (WGs) of the Intergovernmental Panel on Climate Change (IPCC). It provides an integrated view of climate change as the final part of the IPCC's Fourth Assessment Report (AR4).

Topic 1 summarises observed changes in climate and their effects on natural and human systems, regardless of their causes, while Topic 2 assesses the causes of the observed changes. Topic 3 presents projections of future climate change and related impacts under different scenarios.

Topic 4 discusses adaptation and mitigation options over the next few decades and their interactions with sustainable development. Topic 5 assesses the relationship between adaptation and mitigation on a more conceptual basis and takes a longer-term perspective. Topic 6 summarises the major robust findings and remaining key uncertainties in this assessment.

A schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages, is shown in Figure I.1. At the time of the Third Assessment Report (TAR) in 2001, information was mainly available to describe the linkages clockwise, i.e. to derive climatic changes and impacts from socio-economic information and emissions. With increased understanding of these linkages, it is now possible to assess the linkages also counterclockwise, i.e. to evaluate possible development pathways and global emissions constraints that would reduce the risk of future impacts that society may wish to avoid.

Schematic framework of anthropogenic climate change drivers, impacts and responses

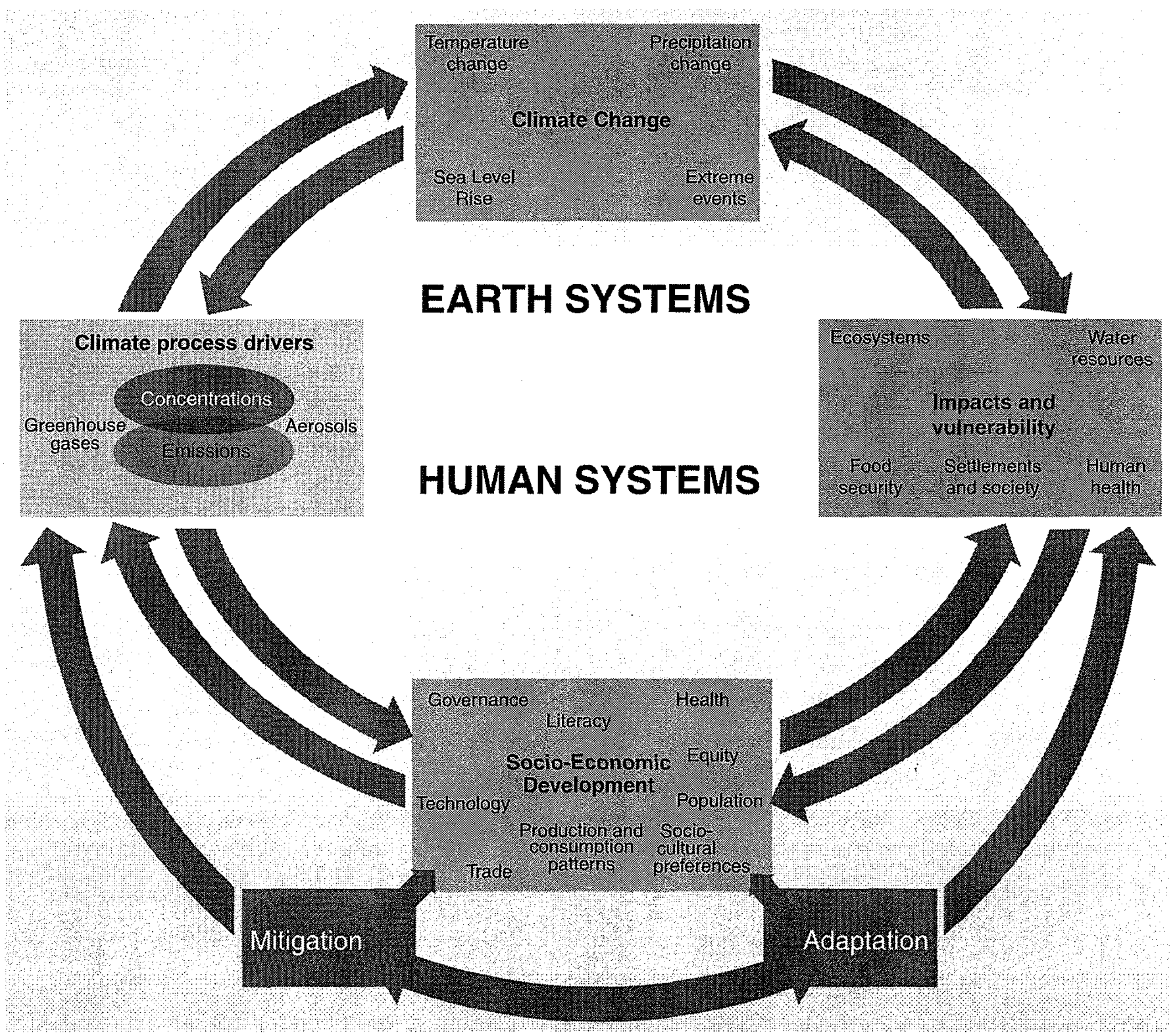


Figure I.1. Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages.

Treatment of uncertainty

The IPCC uncertainty guidance note[1] defines a framework for the treatment of uncertainties across all WGs and in this Synthesis Report. This framework is broad because the WGs assess material from different disciplines and cover a diversity of approaches to the treatment of uncertainty drawn from the literature. The nature of data, indicators and analyses used in the natural sciences is generally different from that used in assessing technology development or the social sciences. WG I focuses on the former, WG III on the latter, and WG II covers aspects of both.

Three different approaches are used to describe uncertainties each with a distinct form of language. Choices among and within these three approaches depend on both the nature of the information available and the authors' expert judgment of the correctness and completeness of current scientific understanding.

Where uncertainty is assessed qualitatively, it is characterised by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III through a series of self-explanatory terms such as: *high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc.*

Where uncertainty is assessed more quantitatively using expert judgement of the correctness of underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: *very high confidence* at least 9 out of 10; *high confidence* about 8 out of 10; *medium confidence* about 5 out of 10; *low confidence* about 2 out of 10; and *very low confidence* less than 1 out of 10.

Where uncertainty in specific outcomes is assessed using expert judgment and statistical analysis of a body of evidence (e.g. observations or model results), then the following likelihood ranges are used to express the assessed probability of occurrence: *virtually certain* >99%; *extremely likely* >95%; *very likely* >90%; *likely* >66%; *more likely than not* > 50%; *about as likely as not* 33% to 66%; *unlikely* <33%; *very unlikely* <10%; *extremely unlikely* <5%; *exceptionally unlikely* <1%.

WG II has used a combination of confidence and likelihood assessments and WG I has predominantly used likelihood assessments.

This Synthesis Report follows the uncertainty assessment of the underlying WGs. Where synthesised findings are based on information from more than one WG, the description of uncertainty used is consistent with that for the components drawn from the respective WG reports.

Unless otherwise stated, numerical ranges given in square brackets in this report indicate 90% uncertainty intervals (i.e. there is an estimated 5% likelihood that the value could be above the range given in square brackets and 5% likelihood that the value could be below that range). Uncertainty intervals are not necessarily symmetric around the best estimate.

[1] See http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/uncertainty-guidance-note.pdf

1

Observed changes in climate and their effects

1.1 Observations of climate change

Since the TAR, progress in understanding how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analyses, broader geographical coverage, better understanding of uncertainties and a wider variety of measurements. *{WGI SPM}*

Definitions of climate change

Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), where climate change refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Figure 1.1). ***{WGI 3.2, 4.8, 5.2, 5.5, SPM}***

Eleven of the last twelve years (1995-2006) rank among the twelve warmest years in the instrumental record of global surface temperature (since 1850). The 100-year linear trend (1906-2005) of 0.74 [0.56 to 0.92]°C is larger than the corresponding trend of 0.6 [0.4 to 0.8]°C (1901-2000) given in the TAR (Figure 1.1). The linear warming trend over the 50 years from 1956 to 2005 (0.13 [0.10 to 0.16]°C per decade) is nearly twice that for the 100 years from 1906 to 2005. *{WGI 3.2, SPM}*

The temperature increase is widespread over the globe and is greater at higher northern latitudes (Figure 1.2). Average Arctic temperatures have increased at almost twice the global average rate in the past 100 years. Land regions have warmed faster than the oceans (Figures 1.2 and 2.5). Observations since 1961 show that the average temperature of the global ocean has increased to depths of at least 3000m and that the ocean has been taking up over 80% of the heat being added to the climate system. New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature. *{WGI 3.2, 3.4, 5.2, SPM}*

Increases in sea level are consistent with warming (Figure 1.1). Global average sea level rose at an average rate of 1.8 [1.3 to 2.3]mm per year over 1961 to 2003 and at an average rate of about 3.1 [2.4 to 3.8]mm per year from 1993 to 2003. Whether this faster rate for 1993 to 2003 reflects decadal variation or an increase in the longer-term trend is unclear. Since 1993 thermal expansion of the oceans has contributed about 57% of the sum of the estimated individual contributions to the sea level rise, with decreases in glaciers and ice caps contributing about 28% and losses from the polar ice sheets contributing the remainder. From 1993 to 2003 the sum of these climate contributions is consistent within uncertainties with the total sea level rise that is directly observed. *{WGI 4.6, 4.8, 5.5, SPM, Table SPM.1}*

Observed decreases in snow and ice extent are also consistent with warming (Figure 1.1). Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7 [2.1 to 3.3]% per decade, with larger decreases in summer of 7.4 [5.0 to 9.8]% per decade. Mountain glaciers and snow cover on average have declined in both hemispheres. The maximum areal extent of seasonally frozen ground has decreased by about 7% in the Northern Hemisphere since 1900, with decreases in spring of up to 15%. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic by up to 3°C. *{WGI 3.2, 4.5, 4.6, 4.7, 4.8, 5.5, SPM}*

At continental, regional and ocean basin scales, numerous long-term changes in other aspects of climate have also been observed. Trends from 1900 to 2005 have been observed in precipitation amount in many large regions. Over this period, precipitation increased significantly in eastern parts of North and South America, northern Europe and northern and central Asia whereas precipitation declined in the Sahel, the Mediterranean, southern Africa and parts of southern Asia. Globally, the area affected by drought has *likely*[2] increased since the 1970s. *{WGI 3.3, 3.9, SPM}*

Some extreme weather events have changed in frequency and/or intensity over the last 50 years:

- It is *very likely* that cold days, cold nights and frosts have become less frequent over most land areas, while hot days and hot nights have become more frequent. *{WGI 3.8, SPM}*
- It is *likely* that heat waves have become more frequent over most land areas. *{WGI 3.8, SPM}*
- It is *likely* that the frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) has increased over most areas. *{WGI 3.8, 3.9, SPM}*
- It is *likely* that the incidence of extreme high sea level[3] has increased at a broad range of sites worldwide since 1975. *{WGI 5.5, SPM}*

There is observational evidence of an increase in intense tropical cyclone activity in the North Atlantic since about 1970, and suggestions of increased intense tropical cyclone activity in some other regions where concerns over data quality are greater. Multi-decadal variability and the quality of the tropical cyclone records prior to routine satellite observations in about 1970 complicate the detection of long-term trends in tropical cyclone activity. *{WGI 3.8, SPM}*

Average Northern Hemisphere temperatures during the second half of the 20th century were *very likely* higher than during any other 50-year period in the last 500 years and *likely* the highest in at least the past 1300 years. *{WGI 6.6, SPM}*

[2] Likelihood and confidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

[3] Excluding tsunamis, which are not due to climate change. Extreme high sea level depends on average sea level and on regional weather systems. It is defined here as the highest 1% of hourly values of observed sea level at a station for a given reference period.

Changes in temperature, sea level and Northern Hemisphere snow cover

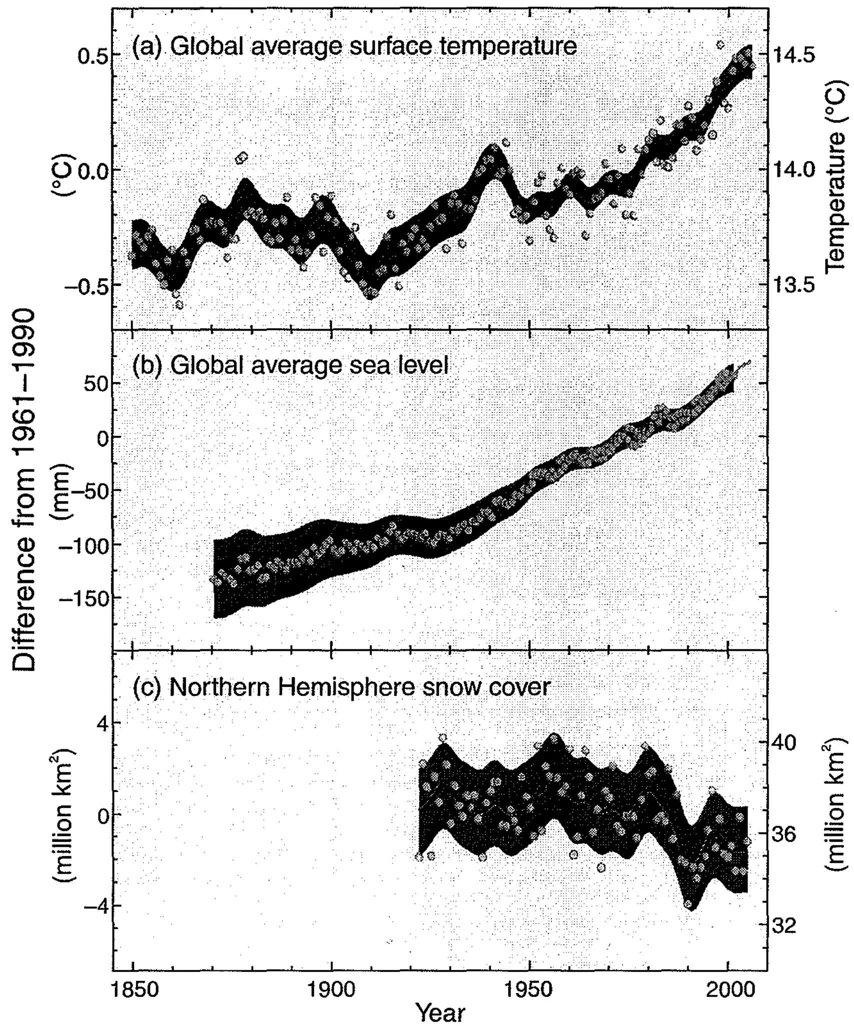


Figure 1.1. *Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data; and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {WGI FAQ 3.1 Figure 1, Figure 4.2, Figure 5.13, Figure SPM.3}*

1.2 Observed effects of climate changes

The statements presented here are based largely on data sets that cover the period since 1970. The number of studies of observed trends in the physical and biological environment and their relationship to regional climate changes has increased greatly since the TAR. The quality of the data sets has also improved. There is a notable lack of geographic balance in data and literature on observed changes, with marked scarcity in developing countries. *{WGII SPM}*

These studies have allowed a broader and more confident assessment of the relationship between observed warming and impacts than was made in the TAR. That assessment concluded that "there is *high confidence*[2] that recent regional changes in temperature have had discernible impacts on physical and biological systems". *{WGII SPM}*

Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. *{WGII SPM}*

There is *high confidence* that natural systems related to snow, ice and frozen ground (including permafrost) are affected. Examples are:

- enlargement and increased numbers of glacial lakes *{WGII 1.3, SPM}*
- increasing ground instability in permafrost regions and rock avalanches in mountain regions *{WGII 1.3, SPM}*
- changes in some Arctic and Antarctic ecosystems, including those in sea-ice biomes, and predators at high levels of the food web. *{WGII 1.3, 4.4, 15.4, SPM}*

Based on growing evidence, there is *high confidence* that the following effects on hydrological systems are occurring: increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers in many regions, with effects on thermal structure and water quality. *{WGII 1.3, 15.2, SPM}*

Changes in physical and biological systems and surface temperature 1970-2004

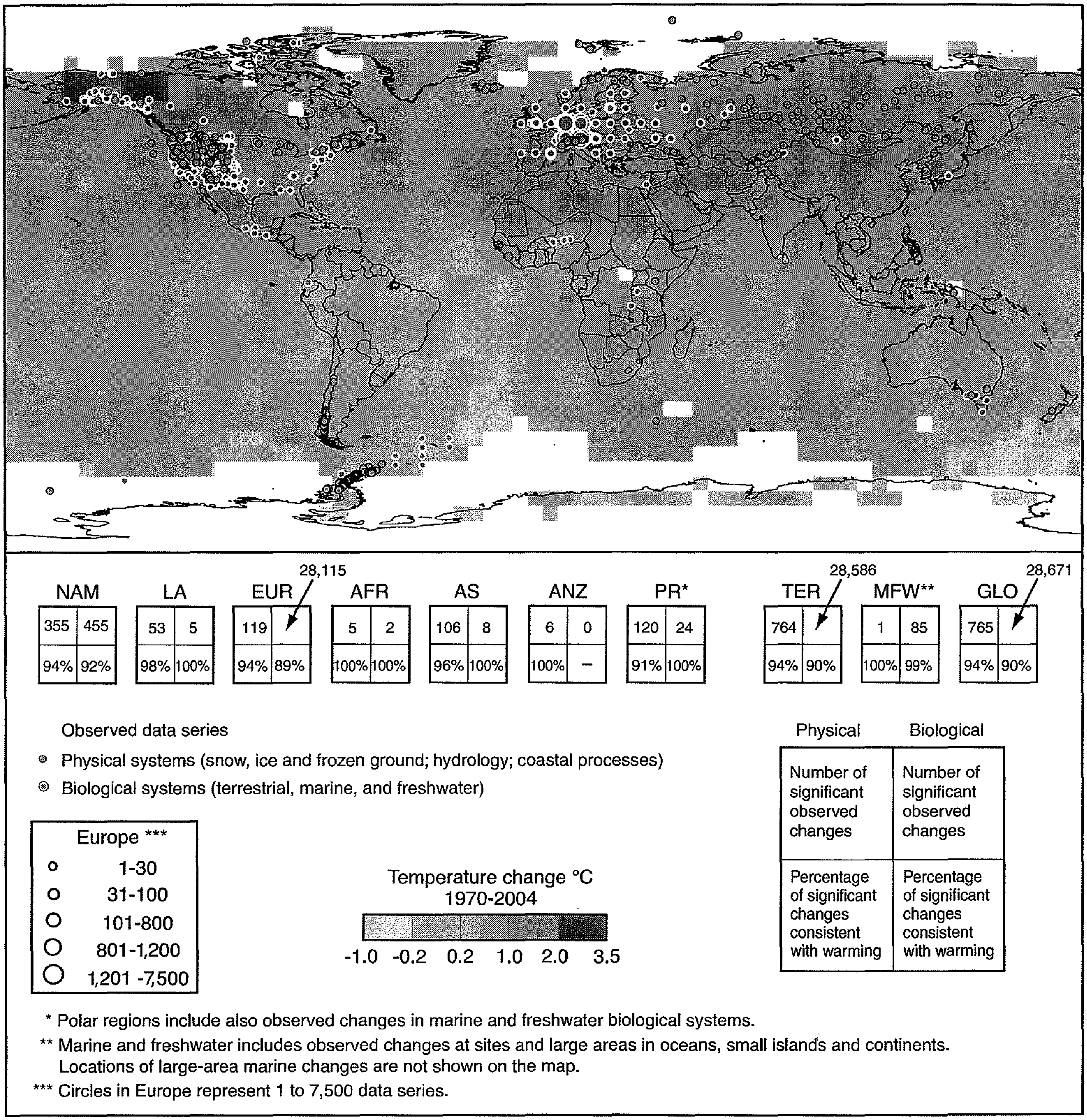


Figure 1.2. *Locations of significant changes in data series of physical systems (snow, ice and frozen ground; hydrology; and coastal processes) and biological systems (terrestrial, marine, and freshwater biological systems), are shown together with surface air temperature changes over the period 1970-2004. A subset of about 29,000 data series was selected from about 80,000 data series from 577 studies. These met the following criteria: (1) ending in 1990 or later; (2) spanning a period of at least 20 years; and (3) showing a significant change in either direction, as assessed in individual studies. These data series are from about 75 studies (of which about 70 are new since the TAR) and contain about 29,000 data series, of which about 28,000 are from European studies. White areas do not contain sufficient observational climate data to estimate a temperature trend. The 2 x 2 boxes show the total number of data series with significant changes (top row) and the percentage of those consistent with warming (bottom row) for (i) continental regions: North America (NAM), Latin America (LA), Europe (EUR), Africa (AFR), Asia (AS), Australia and New Zealand (ANZ), and Polar Regions (PR) and (ii) global-scale: Terrestrial (TER), Marine and Freshwater (MFW), and Global (GLO). The numbers of studies from the seven regional boxes (NAM, ..., PR) do not add up to the global (GLO) totals because numbers from regions except Polar do not include the numbers related to Marine and Freshwater (MFW) systems. Locations of large-area marine changes are not shown on the map. {WGII Figure SPM.1, Figure 1.8, Figure 1.9; WGI Figure 3.9b}*

There is *very high confidence*, based on more evidence from a wider range of species, that recent warming is strongly affecting terrestrial biological systems, including such changes as earlier timing of spring events, such as leaf-unfolding, bird migration and egg-laying; and poleward and upward shifts in ranges in plant and animal species. Based on satellite observations since the early 1980s, there is *high confidence* that there has been a trend in many regions towards earlier 'greening' of vegetation in the spring linked to longer thermal growing seasons due to recent warming. *{WGII 1.3, 8.2, 14.2, SPM}*

There is *high confidence*, based on substantial new evidence, that observed changes in marine and freshwater biological systems are associated with rising water temperatures, as well as related changes in ice cover, salinity, oxygen levels and circulation. These include: shifts in ranges and changes in algal, plankton and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers. While there is increasing evidence of climate change impacts on coral reefs, separating the impacts of climate-related stresses from other stresses (e.g. overfishing and pollution) is difficult. *{WGII 1.3, SPM}*

Other effects of regional climate changes on natural and human environments are emerging, although many are difficult to discern due to adaptation and non-climatic drivers. ***{WGII SPM}***

Effects of temperature increases have been documented with *medium confidence* in the following managed and human systems:

- agricultural and forestry management at Northern Hemisphere higher latitudes, such as earlier spring planting of crops, and alterations in disturbances of forests due to fires and pests *{WGII 1.3, SPM}*
- some aspects of human health, such as excess heat-related mortality in Europe, changes in infectious disease vectors in parts of Europe, and earlier onset of and increases in seasonal production of allergenic pollen in Northern Hemisphere high and mid-latitudes *{WGII 1.3, 8.2, 8.ES, SPM}*
- some human activities in the Arctic (e.g. hunting and shorter travel seasons over snow and ice) and in lower-elevation alpine areas (such as limitations in mountain sports). *{WGII 1.3, SPM}*

Sea level rise and human development are together contributing to losses of coastal wetlands and mangroves and increasing damage from coastal flooding in many areas. However, based on the published literature, the impacts have not yet become established trends. *{WGII 1.3, 1.ES, SPM}*

1.3 Consistency of changes in physical and biological systems with warming

Changes in the ocean and on land, including observed decreases in snow cover and Northern Hemisphere sea ice extent, thinner sea ice, shorter freezing seasons of lake and river ice, glacier melt, decreases in permafrost extent, increases in soil temperatures and borehole temperature profiles, and sea level rise, provide additional evidence that the world is warming. *{WGI 3.9}*

Of the more than 29,000 observational data series, from 75 studies, that show significant change in many physical and biological systems, more than 89% are consistent with the direction of change expected as a response to warming (Figure 1.2). *{WGII 1.4, SPM}*

1.4 Some aspects of climate have not been observed to change

Some aspects of climate appear not to have changed and, for some, data inadequacies mean that it cannot be determined if they have changed. Antarctic sea ice extent shows inter-annual variability and localised changes but no statistically significant average multi-decadal trend, consistent with the lack of rise in near-surface atmospheric temperatures averaged across the continent. There is insufficient evidence to determine whether trends exist in some other variables, for example the meridional overturning circulation (MOC) of the global ocean or small-scale phenomena such as tornadoes, hail, lightning and dust storms. There is no clear trend in the annual numbers of tropical cyclones. *{WGI 3.2, 3.8, 4.4, 5.3, SPM}*

2

Causes of change

Causes of change

This Topic considers both natural and anthropogenic drivers of climate change, including the chain from greenhouse gas (GHG) emissions to atmospheric concentrations to radiative forcing[4] to climate responses and effects.

2.1 Emissions of long-lived GHGs

The radiative forcing of the climate system is dominated by the long-lived GHGs, and this section considers those whose emissions are covered by the UNFCCC.

Global GHG emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004 (Figure 2.1).[5] *{WGIII 1.3, SPM}*

Carbon dioxide (CO_2) is the most important anthropogenic GHG. Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthropogenic GHG emissions in 2004 (Figure 2.1). The rate of growth of CO_2-eq emissions was much higher during the recent 10-year period of 1995-2004 (0.92 $GtCO_2$-eq per year) than during the previous period of 1970-1994 (0.43 $GtCO_2$-eq per year). *{WGIII 1.3, TS.1, SPM}*

Carbon dioxide-equivalent (CO_2-eq) emissions and concentrations

GHGs differ in their warming influence (radiative forcing) on the global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences may be expressed through a common metric based on the radiative forcing of CO_2.

- ***CO_2-equivalent emission*** is the amount of CO_2 emission that would cause the same time-integrated radiative forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon.[6] For a mix of GHGs it is obtained by summing the equivalent CO_2 emissions of each gas. Equivalent CO_2 emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses (see WGI 2.10).
- ***CO_2-equivalent concentration*** is the concentration of CO_2 that would cause the same amount of radiative forcing as a given mixture of CO_2 and other forcing components.[7]

The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate. The

Global anthropogenic GHG emissions

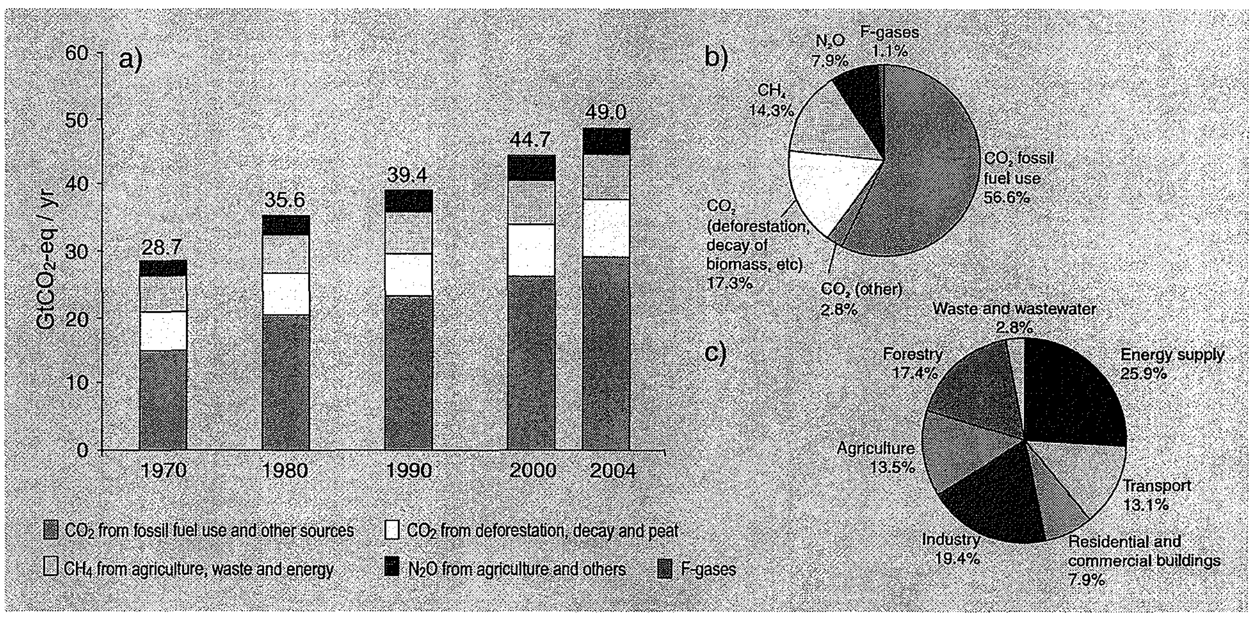


Figure 2.1. *(a) Global annual emissions of anthropogenic GHGs from 1970 to 2004.[5] (b) Share of different anthropogenic GHGs in total emissions in 2004 in terms of CO_2-eq. (c) Share of different sectors in total anthropogenic GHG emissions in 2004 in terms of CO_2-eq. (Forestry includes deforestation.) {WGIII Figures TS.1a, TS.1b, TS.2b}*

[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. In this report radiative forcing values are for changes relative to pre-industrial conditions defined at 1750 and are expressed in watts per square metre (W/m^2).

[5] Includes only carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphurhexafluoride (SF_6), whose emissions are covered by the UNFCCC. These GHGs are weighted by their 100-year Global Warming Potentials (GWPs), using values consistent with reporting under the UNFCCC.

[6] This report uses 100-year GWPs and numerical values consistent with reporting under the UNFCCC.

[7] Such values may consider only GHGs, or a combination of GHGs and aerosols.

sectoral sources of GHGs in 2004 are considered in Figure 2.1c. *{WGIII 1.3, SPM}*

The effect on global emissions of the decrease in global energy intensity (-33%) during 1970 to 2004 has been smaller than the combined effect of global income growth (77%) and global population growth (69%); both drivers of increasing energy-related CO_2 emissions. The long-term trend of declining CO_2 emissions per unit of energy supplied reversed after 2000. *{WGIII 1.3, Figure SPM.2, SPM}*

Differences in per capita income, per capita emissions and energy intensity among countries remain significant. In 2004, UNFCCC Annex I countries held a 20% share in world population, produced 57% of the world's Gross Domestic Product based on Purchasing Power Parity (GDP_{ppp}) and accounted for 46% of global GHG emissions (Figure 2.2). *{WGIII 1.3, SPM}*

2.2 Drivers of climate change

Changes in the atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change. They affect the absorption, scattering and emission of radiation within the atmosphere and at the Earth's surface. The resulting positive or negative changes in energy balance due to these factors are expressed as radiative forcing[4], which is used to compare warming or cooling influences on global climate. *{WGI TS.2}*

Human activities result in emissions of four long-lived GHGs: CO_2, methane (CH_4), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine). Atmospheric concentrations of GHGs increase when emissions are larger than removal processes.

Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values determined from ice cores spanning many thousands of years (Figure 2.3). The atmospheric concentrations of CO_2 and CH_4 in 2005 exceed by far the natural range over the last 650,000 years. Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is *very likely* that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture. ***{WGI 2.3, 7.3, SPM}***

The global atmospheric concentration of CO_2 increased from a pre-industrial value of about 280ppm to 379ppm in 2005. The annual CO_2 concentration growth rate was larger during the last 10 years (1995-2005 average: 1.9ppm per year) than it has been since the beginning of continuous direct atmospheric measurements (1960-2005 average: 1.4ppm per year), although there is year-to-year variability in growth rates. *{WGI 2.3, 7.3, SPM; WGIII 1.3}*

The global atmospheric concentration of CH_4 has increased from a pre-industrial value of about 715ppb to 1732ppb in the early 1990s, and was 1774ppb in 2005. Growth rates have declined since the early 1990s, consistent with total emissions (sum of anthropogenic and natural sources) being nearly constant during this period. *{WGI 2.3, 7.4, SPM}*

The global atmospheric N_2O concentration increased from a pre-industrial value of about 270ppb to 319ppb in 2005. *{WGI 2.3, 7.4, SPM}*

Many halocarbons (including hydrofluorocarbons) have increased from a near-zero pre-industrial background concentration, primarily due to human activities. *{WGI 2.3, SPM; SROC SPM}*

There is *very high confidence* that the global average net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4] W/m² (Figure 2.4). ***{WGI 2.3, 6.5, 2.9, SPM}***

The combined radiative forcing due to increases in CO_2, CH_4 and N_2O is +2.3 [+2.1 to +2.5] W/m², and its rate of increase during

Regional distribution of GHG emissions by population and by GDP_{PPP}

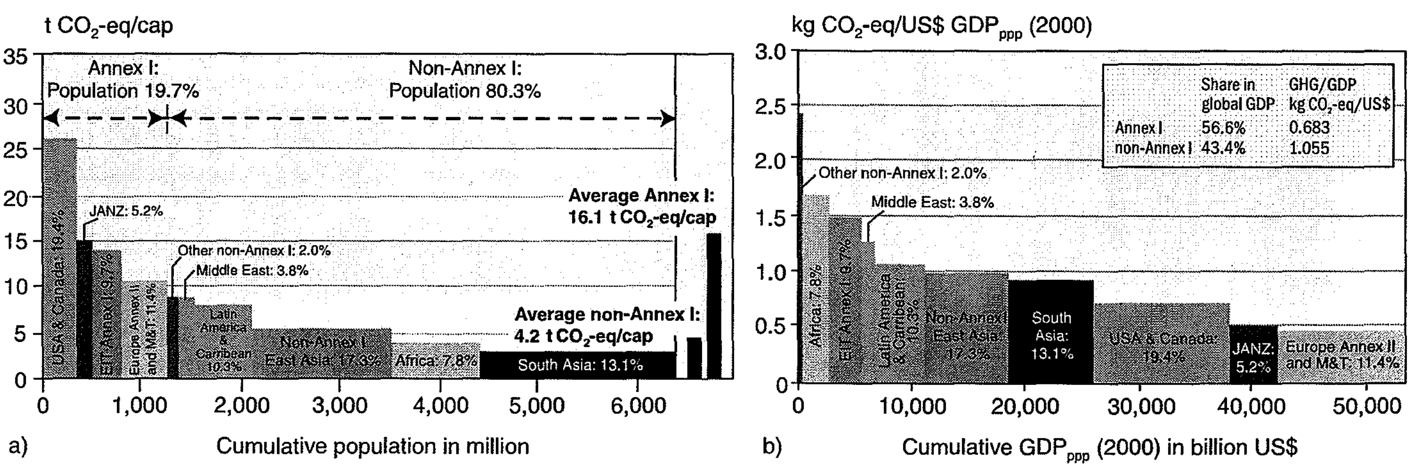


Figure 2.2. (a) Distribution of regional per capita GHG emissions according to the population of different country groupings in 2004 (see appendix for definitions of country groupings). (b) Distribution of regional GHG emissions per US$ of GDP_{PPP} over the GDP of different country groupings in 2004. The percentages in the bars in both panels indicate a region's share in global GHG emissions. {WGIII Figures SPM.3a, SPM.3b}

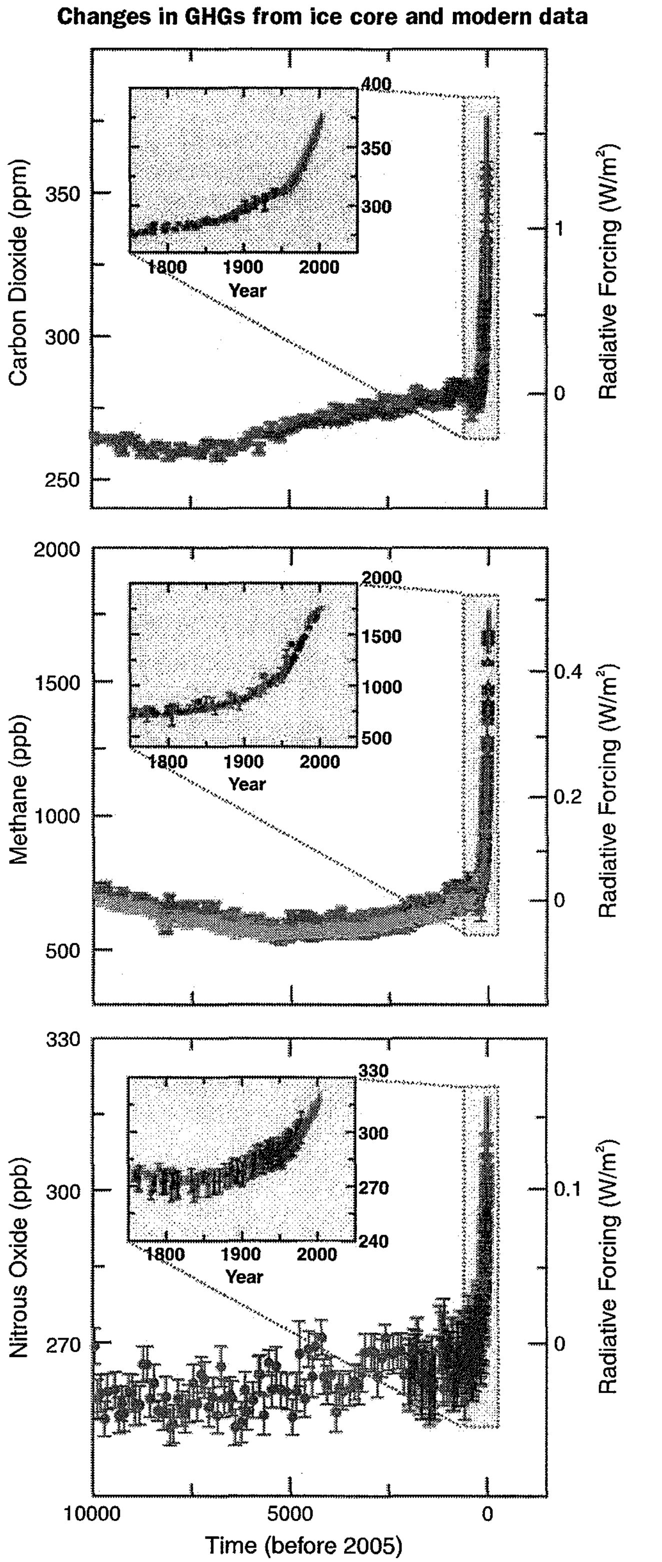


Figure 2.3. Atmospheric concentrations of CO_2, CH_4 and N_2O over the last 10,000 years (large panels) and since 1750 (inset panels). Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). The corresponding radiative forcings relative to 1750 are shown on the right hand axes of the large panels. {WGI Figure SPM.1}

the industrial era is *very likely* to have been unprecedented in more than 10,000 years (Figures 2.3 and 2.4). The CO_2 radiative forcing increased by 20% from 1995 to 2005, the largest change for any decade in at least the last 200 years. *{WGI 2.3, 6.4, SPM}*

Anthropogenic contributions to aerosols (primarily sulphate, organic carbon, black carbon, nitrate and dust) together produce a cooling effect, with a total direct radiative forcing of -0.5 [-0.9 to -0.1] W/m² and an indirect cloud albedo forcing of -0.7 [-1.8 to -0.3] W/m². Aerosols also influence precipitation. *{WGI 2.4, 2.9, 7.5, SPM}*

In comparison, changes in solar irradiance since 1750 are estimated to have caused a small radiative forcing of +0.12 [+0.06 to +0.30] W/m², which is less than half the estimate given in the TAR. *{WGI 2.7, SPM}*

2.3 Climate sensitivity and feedbacks

The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is defined as the equilibrium global average surface warming following a doubling of CO_2 concentration. Progress since the TAR enables an assessment that climate sensitivity is *likely* to be in the range of 2 to 4.5°C with a best estimate of about 3°C, and is *very unlikely* to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. *{WGI 8.6, 9.6, Box 10.2, SPM}*

Feedbacks can amplify or dampen the response to a given forcing. Direct emission of water vapour (a greenhouse gas) by human activities makes a negligible contribution to radiative forcing. However, as global average temperature increases, tropospheric water vapour concentrations increase and this represents a key positive feedback but not a forcing of climate change. Water vapour changes represent the largest feedback affecting equilibrium climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty. Spatial patterns of climate response are largely controlled by climate processes and feedbacks. For example, sea-ice albedo feedbacks tend to enhance the high latitude response. *{WGI 2.8, 8.6, 9.2, TS.2.1.3, TS.2.5, SPM}*

Warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback leads to larger atmospheric CO_2 increases and greater climate change for a given emissions scenario, but the strength of this feedback effect varies markedly among models. *{WGI 7.3, TS.5.4, SPM; WGII 4.4}*

2.4 Attribution of climate change

Attribution evaluates whether observed changes are quantitatively consistent with the expected response to external forcings (e.g. changes in solar irradiance or anthropogenic GHGs) and inconsistent with alternative physically plausible explanations. *{WGI TS.4, SPM}*

Radiative forcing components

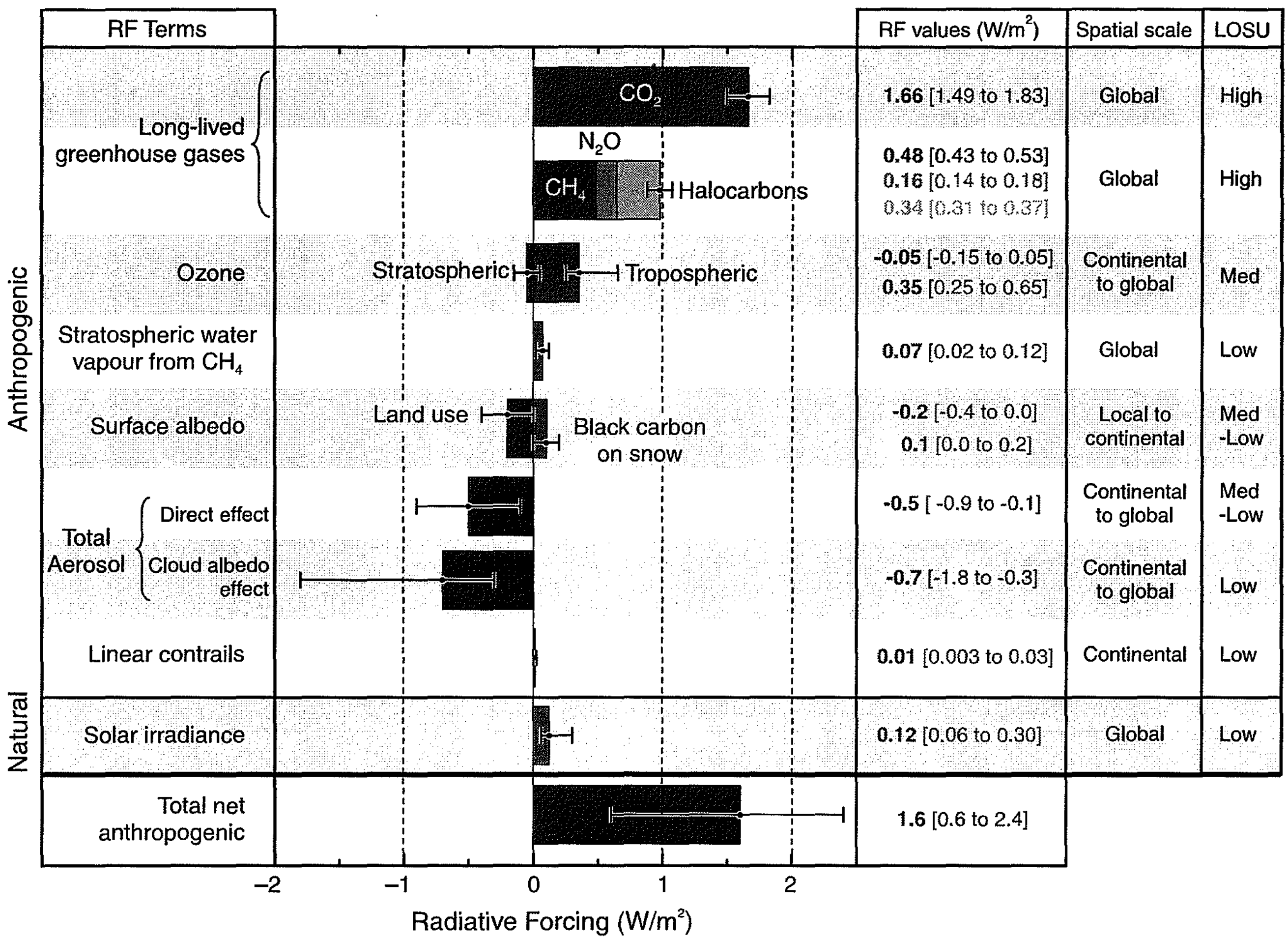


Figure 2.4. Global average radiative forcing (RF) in 2005 (best estimates and 5 to 95% uncertainty ranges) with respect to 1750 for CO_2, CH_4, N_2O and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). Aerosols from explosive volcanic eruptions contribute an additional episodic cooling term for a few years following an eruption. The range for linear contrails does not include other possible effects of aviation on cloudiness. {WGI Figure SPM.2}

Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic GHG concentrations.[8] This is an advance since the TAR's conclusion that "most of the observed warming over the last 50 years is *likely* to have been due to the increase in GHG concentrations" (Figure 2.5). ***{WGI 9.4, SPM}***

The observed widespread warming of the atmosphere and ocean, together with ice mass loss, support the conclusion that it is *extremely unlikely* that global climate change of the past 50 years can be explained without external forcing and *very likely* that it is not due to known natural causes alone. During this period, the sum of solar and volcanic forcings would *likely* have produced cooling, not warming. Warming of the climate system has been detected in changes in surface and atmospheric temperatures and in temperatures of the upper several hundred metres of the ocean. The observed pattern of tropospheric warming and stratospheric cooling is *very likely* due to the combined influences of GHG increases and stratospheric ozone depletion. It is *likely* that increases in GHG concentrations alone would have caused more warming than observed because volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place. *{WGI 2.9, 3.2, 3.4, 4.8, 5.2, 7.5, 9.4, 9.5, 9.7, TS.4.1, SPM}*

It is *likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica) (Figure 2.5). ***{WGI 3.2, 9.4, SPM}***

The observed patterns of warming, including greater warming over land than over the ocean, and their changes over time, are simulated only by models that include anthropogenic forcing. No coupled global climate model that has used natural forcing only has reproduced the continental mean warming trends in individual continents (except Antarctica) over the second half of the 20th century. *{WGI 3.2, 9.4, TS.4.2, SPM}*

[8] Consideration of remaining uncertainty is based on current methodologies.

tal temperature change

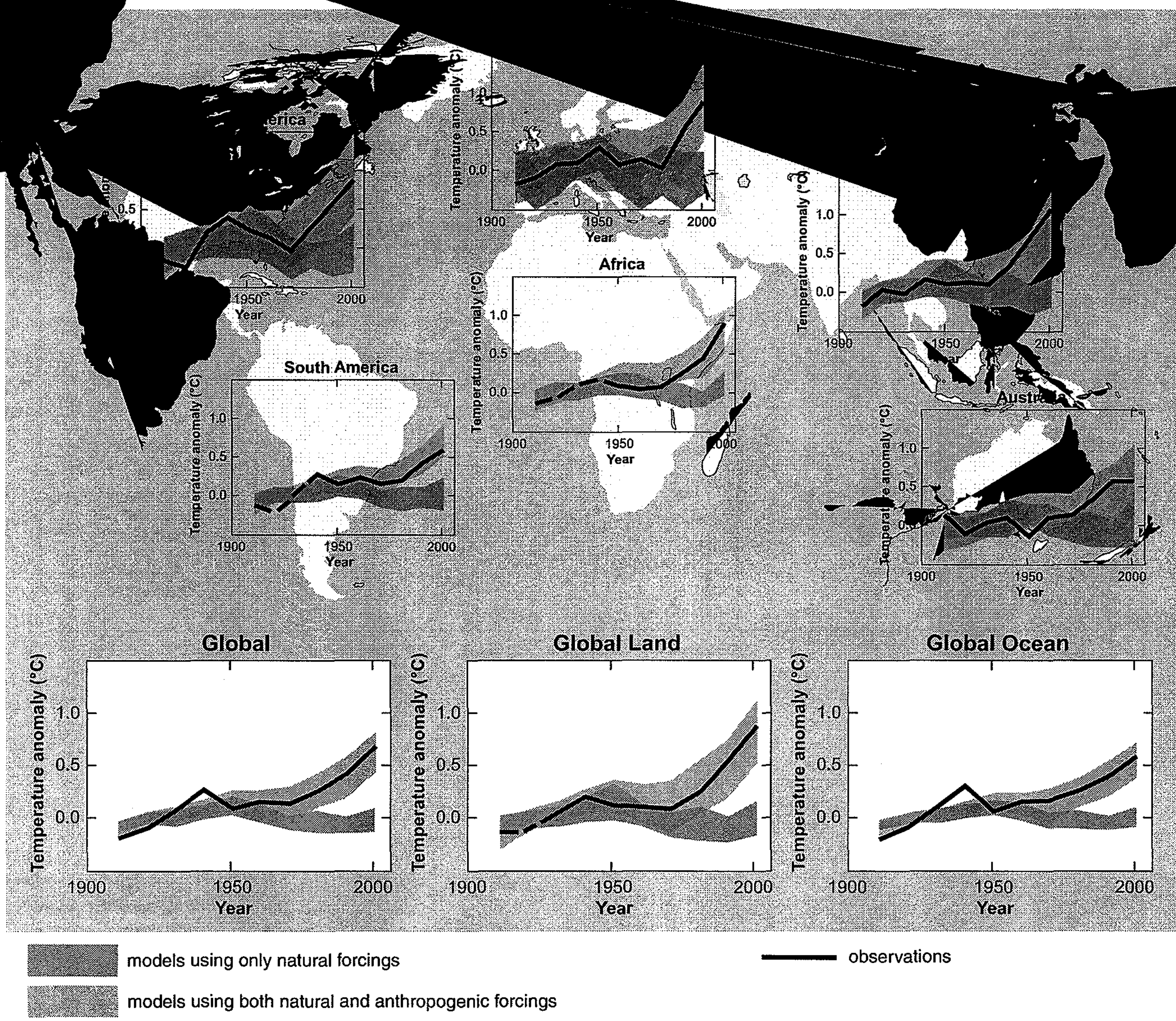


Figure 2.5. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings. {WGI Figure SPM.4}

Difficulties remain in simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively larger, making it harder to distinguish changes expected due to external forcings. Uncertainties in local forcings, such as those due to aerosols and land-use change, and feedbacks also make it difficult to estimate the contribution of GHG increases to observed small-scale temperature changes. *{WGI 8.3, 9.4, SPM}*

Advances since the TAR show that discernible human influences extend beyond average temperature to other aspects of climate, including temperature extremes and wind patterns. ***{WGI 9.4, 9.5, SPM}***

Temperatures of the most extreme hot nights, cold nights and cold days are *likely* to have increased due to anthropogenic forcing. It is *more likely than not* that anthropogenic forcing has increased the risk of heat waves. Anthropogenic forcing is *likely* to have contributed to changes in wind patterns, affecting extra-tropical storm tracks and temperature patterns in both hemispheres. However, the observed changes in the Northern Hemisphere circulation are larger than simulated by models in response to 20th century forcing change. *{WGI 3.5, 3.6, 9.4, 9.5, 10.3, SPM}*

It is *very likely* that the response to anthropogenic forcing contributed to sea level rise during the latter half of the 20th century. There is some evidence of the impact of human climatic influence on the hydrological cycle, including the observed large-scale patterns of changes in land precipitation over the 20th century. It is *more likely than not* that human influence has contributed to a global trend towards increases in area affected by drought since the 1970s and the frequency of heavy precipitation events. *{WGI 3.3, 5.5, 9.5, TS.4.1, TS.4.3}*

Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. ***{WGII 1.4}***

A synthesis of studies strongly demonstrates that the spatial agreement between regions of significant warming across the globe and the locations of significant observed changes in many natural systems consistent with warming is *very unlikely* to be due solely to natural variability of temperatures or natural variability of the systems. Several modelling studies have linked some specific responses in physical and biological systems to anthropogenic warming, but only a few such studies have been performed. Taken together with evidence of significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica), it is *likely* that anthropogenic warming over the last three decades has had a discernible influence on many natural systems. *{WGI 3.2, 9.4, SPM; WGII 1.4, SPM}*

Limitations and gaps currently prevent more complete attribution of the causes of observed natural system responses to anthropogenic warming. The available analyses are limited in the number of systems, length of records and locations considered. Natural temperature variability is larger at the regional than the global scale, thus affecting identification of changes to external forcing. At the regional scale, other non-climate factors (such as land-use change, pollution and invasive species) are influential. *{WGII 1.2, 1.3, 1.4, SPM}*

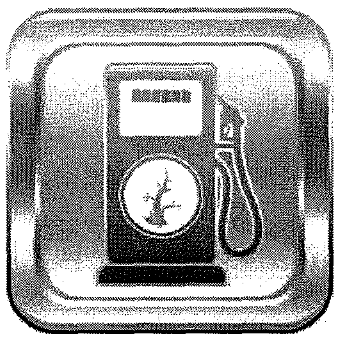
Exhibit 2

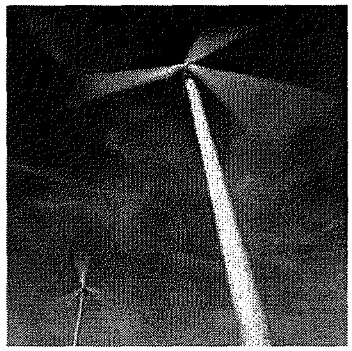
ECONOMIC FORUM

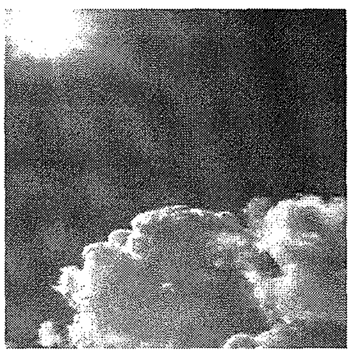
COMMITTED TO IMPROVING THE STATE OF THE WORLD

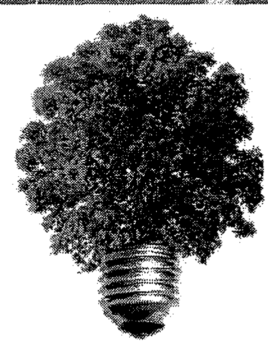
Green Investing

Towards a Clean Energy Infrastructure









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ECONOMIC FORUM
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Contents

Preface

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The World Economic Forum is proud to release this report as part of our Green Investing project. The Green Investing project, which was mandated by the Forum's Investors community at the World Economic Forum Annual Meeting in Davos in January 2008, aims to explore ways in which the world's leading investors can most effectively engage in the global effort to address climate change.

The investment volumes required to avoid the catastrophic impact of climate change are substantial and success will largely depend on the successful mobilization of both the public and private sectors. This report highlights viable business opportunities in the energy sector that could have high abatement potential, while enabling investors to sustain their long-term corporate assets and shareholder value. Furthermore, the report aims to identify policy recommendations that could potentially enable the efficient deployment of further necessary private capital.

Over the past year we have witnessed a severe global financial crisis. As the effects of the financial crisis continue to unfold, the world faces serious challenges to both capital markets and the global economy. There is significant risk of a severe global recession that will affect many sectors, asset classes and regions in tandem.

It is in this context that the World Economic Forum is releasing this report. Its launch is timed to coincide with the World Economic Forum Annual Meeting 2009. Leaders from industry, government, civil society and other key sectors will have a unique and timely opportunity to actively shape the post-crisis world in a holistic and systematic manner. It is crucial that the environmental challenges are not left aside when focusing on stabilizing the global financial system and reviving global economic growth. Waiting for economic recovery, rather than taking decisive action now, will make the future climate challenge far greater. To this end, we hope that this report will stimulate informed dialogue among stakeholders on the opportunities that will emerge from a move towards a resilient and sustained low-carbon economy.

The Green Investing project is conducted in conjunction with the Forum's broader Copenhagen Climate Change Initiative which will bring together business leaders, government representatives and world-class experts to help catalyse a practical, focused public-private dialogue on climate change to complement the United Nations negotiation process.

Guidance was provided by an actively involved Committee of Experts which included:

- **Morgan Bazilian,** Special Advisor on Energy and Climate Change, Department of Energy, Ireland
- **Marcel Brenninkmeijer,** Chairman, Good Energies AG
- **Wes Edens,** Chairman and Chief Executive Officer, Fortress Investment LLC
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On behalf of the World Economic Forum, we wish to thank New Energy Finance, in particular Michael Liebreich, Chris Greenwood and Alice Hohler, and the members of the Expert Committee for supporting us in the creation of this report. We would like to acknowledge the P8 Group and Heidrick and Struggles' contribution to the project. Last but not least, we are grateful to the many individuals who responded to our invitation to participate in workshops and interviews and who gave so generously of their time, energy and insights.

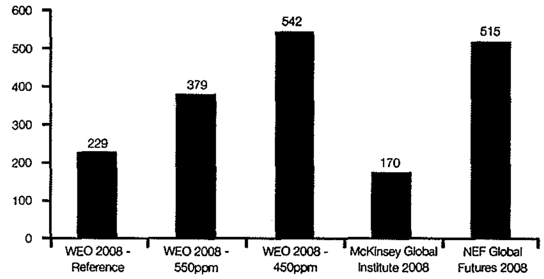
1. Executive Summary

Investors and policy-makers are facing an historic choice. At the very time when commentators are branding green investing as a luxury the world cannot afford, enormous investment in the world's energy infrastructure is required in order to address the twin threats of energy insecurity and climate change. Waiting for economic recovery, rather than taking decisive action now, will make the future challenge far greater. As the cost of clean energy technologies decreases and policy support is put in place, the shape of the eventual energy system is emerging. But the investment demand is substantial. Despite the recent turmoil, the world's financial markets are up to the financing challenge, but they will need continued action from the world's policy-makers and leading corporations.

We are not going to rehearse the science of climate change in this paper. Suffice to say, the most recent data show carbon and temperature trajectories tracking the pessimistic edge of the scenarios considered by the Intergovernmental Panel on Climate Change (IPCC), the scientific body set up to advise policy-makers. To have a chance of limiting the average increase in global temperatures to 2°C, a level which an increasing number of experts already considers unsafe, the IPCC believes that we need to limit the concentration of greenhouse gases in the atmosphere to the equivalent of 450 parts per million of carbon dioxide equivalent by volume (450ppm CO_2e) by 2030. This means reducing CO_2 emissions by 60% from baseline levels by 2030.

Energy is responsible for more than 60% of the CO_2 emitted into the atmosphere each year. If we are to limit emissions to a level consistent with 450ppm CO_2e, what is required over the coming few decades is nothing less than a complete restructuring of our energy infrastructure – the fuels we use, how we generate and distribute electricity, how we power our transportation, the way we heat and cool our homes and offices, the way we run our factories[1]. And we have to achieve this without jeopardizing the global growth needed to pull the developing world out of poverty or destroying the accumulated capital formation that is needed to pay pensions and healthcare costs in the developed world.

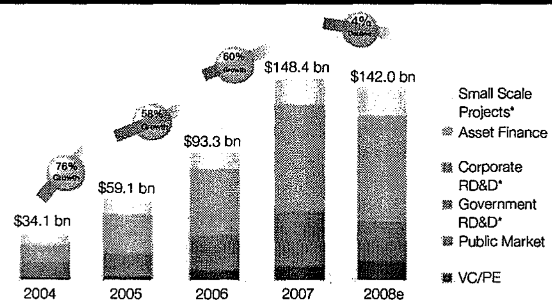
Figure 1: Estimated Clean Energy Annual Investment to 2030, US$ billions



Note: WEO 2008 covers investment in renewable energy generation and energy efficiency, with an assumption that half the additional power investment required under the 550ppm and 450ppm scenarios is in renewable energy; McKinsey covers only energy efficiency investment; New Energy Finance Global Futures covers investment in renewable energy and energy efficiency technologies only.

Source: IEA WEO 2008, McKinsey, New Energy Finance

Figure 2: Total Global New Investment in Clean Energy, 2004-2008, US$ billions



Note: Figures marked * are based on industry estimates from various sources; all others are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database; figures are adjusted to remove double-counting

Source: New Energy Finance

The Scale of Investment Required

The sums involved in a shift to a low-carbon energy system are daunting and there are varying views regarding the exact amount of investment necessary. The Stern Review talks of a cost of 1% of global GDP to limit greenhouse gases to a concentration of 550ppm CO_2e by 2050, equivalent to around US$ 500 billion a year currently (global GDP 2007 was US$ 54 trillion), although the longer the delay in taking decisive action, the higher the cost of mitigation. The International Energy Agency's World Energy Outlook (WEO) 2008 estimates around US$ 550 billion needs to be invested in renewable energy and energy efficiency alone each year between now and 2030 if we are to limit concentrations to 450ppm CO_2e, while New Energy Finance's Global Futures analysis points to an average annual investment of US$ 515 billion over an extended period (see Figure 1).

The good news is that the process of transition and the associated surge in investment have already begun. Investment in clean energy – defined here as investment in renewable energy and energy efficiency technology, but excluding nuclear power and large hydro – increased

[1] For the purpose of this paper we will consider only investment in clean energy (defined here as investment in renewable energy and energy efficiency technology, but excluding nuclear power and large hydro) – although we accept that this forms only a subset of all "Green Investment" opportunities.

from US$ 33 billion to US$ 148 billion between 2004 and 2007 (see Figure 2), and now accounts for around 10% of global energy infrastructure spend. In electricity generation, the rapid expansion of sustainable energy has been even more striking, with 42GW of power generation capacity added in 2007, just under a quarter of the total 190GW of power generation capacity added worldwide.

Eight Emerging Large-Scale Clean Energy Sectors
The four-year surge in investment activity in clean energy has spanned all sectors, all geographies and all asset classes. What has begun to emerge as a result is the overall shape of the new lower-carbon energy infrastructure. No one can describe with certainty what the world's energy system will look like in 2050. A substantial proportion of our energy will undoubtedly still be supplied by fossil fuels, but we can now be fairly certain that a future low-carbon energy system will include a meaningful contribution from the following eight renewable energy sources:

1. Onshore Wind
2. Offshore Wind
3. Solar Photovoltaic (PV)
4. Solar Thermal Electricity Generation (STEG)
5. Municipal Solid Waste-to-Energy (MSW)
6. Sugar-based Ethanol
7. Cellulosic and Next Generation Biofuels
8. Geothermal Power

Although these energy technologies – which constitute only a subset of the full range of opportunities – may not yet be fully cost competitive with fossil fuels, the economics of experience curves and oil and gas depletion are working powerfully to level the playing field. Renewable energy technologies are becoming cheaper as they reach scale and operating experience. This trend has been obscured recently by surging commodity prices and supply chain bottlenecks, but with new industrial capacity coming on-line we are about to see prices drop as they come back in line with costs now that we are moving into a buyer's market. Solar PV electricity costs may become comparable with daytime retail electricity prices in many sunny parts of the world in the next 12 to 36 months, even without subsidies. Wind is already cost competitive with natural gas-fired electricity generation in certain locations without subsidies.

Renewable energy is not generally subject to risks associated with fuel input costs. Increasing fuel prices by 20% increases the costs of generation by 16% for gas and 6% for coal while leaving renewable energy technologies practically untouched. The volatility of fuel prices alone should act to encourage utilities to build some proportion of renewable energy into their portfolios. And higher capital costs for many renewable energy technologies – and no fuel costs – mean that they will benefit more from reductions in effective interest rates than natural gas or coal. Indeed, in a world in which effective interest rates for energy projects drop 300 basis points, while fuel prices and carbon credit prices each rise by 20%, onshore wind becomes cheaper than natural gas, and geothermal and waste-to-energy not only beat natural gas, but are even cheaper than coal-based power.

Nuclear power is also set for a renaissance in many countries around the world. Nuclear's share of total electricity production has remained steady at around 16% since the 1980s. Its contribution is clearly set to grow over the medium to long term, although it will always be limited by issues of cost, storage, safety and public resistance. We do not consider it in detail in this paper.

Key Enablers of a Shift to Clean Energy
The shift to a low-carbon energy system cannot be achieved simply through the addition of new sources of renewable energy. It will also be necessary to make wholesale changes in the way energy is distributed, stored and consumed. Again, the outlines of these changes, and the investment opportunities implied, can already be seen. We focus here on four areas:

1. **Energy Efficiency.** It has been frequently said that the cheapest source of energy is the energy never used. There are enormous opportunities for improving the efficiency of the world's energy infrastructure, both on the supply side and the demand side – and many of them could even produce returns above the cost of capital of major businesses. In a recent report, the McKinsey Global Institute estimated that there are US$ 170 billion of energy efficient investment opportunities that would produce an IRR of 17% or more.
2. **Smart Grid.** The world's electricity grids were designed to distribute power cheaply and reliably from large, centralized, predictable power stations. The grid of the future will have to cope with decentralized, fluctuating supply. It will also be expected to deliver a far more sophisticated range of services to help with demand-side energy management. Only a new and fully digitally-enabled grid architecture will be able to meet these needs, and the investment requirement is estimated by New Energy Finance at US$ 8.6 trillion (including US$ 6.8 trillion to repair and replace the existing transmission and distribution network).
3. **Energy Storage.** The need for energy storage is increasing – whether to power hybrid electric vehicles, to smooth out fluctuations in supply and demand, or to extend appliance functionality. The cost of storing 1MWh of electricity ranges from US$ 50 to US$ 180,

depending on the technology used. As power storage prices come down, it can increasingly be used to smooth the supply of power or to bridge the gap between peak and night-time electricity rates. Improved power storage is also required by ever more advanced mobile appliances and ubiquitous communications.

4. **Carbon Capture and Sequestration.** No discussion of the future energy infrastructure can be complete without considering Carbon Capture and Storage (CCS). Although there are no installations at scale yet, there are almost 200 projects at varying degrees of completion around the globe. With so many countries – including China and the US – overwhelmingly dependent on coal for their electricity, CCS needs to form part of the solution if we are to restrict CO_2e concentrations to 450ppm.

The Role of the Carbon Markets

Although it may sometimes not seem to be the case, we are moving inexorably towards a world in which every major economy puts a price on greenhouse gas emissions. Currently the most liquid markets are the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS) and the global Kyoto compliance markets. Others are following in their footsteps in Australia, Japan, the US's Regional Greenhouse Gas Initiative (RGGI), California and the Western Climate Alliance. Then there is the voluntary market, rapidly taking shape and increasing in volume. These may soon be joined by a US Federal carbon market and a strengthened global scheme may emerge from the negotiations in Copenhagen in 2009.

What we are seeing is the emergence of a system of interlinked policy-led financial markets, similar to currency markets. A single price for carbon everywhere in the world is probably not achievable, but neither is it necessary. As each of these carbon markets grows in liquidity, its rules firm up and become well-understood, and it is linked to other markets via project-based and other mechanisms, arbitrage will reveal a global carbon price range – and it will be one that drives significant behavioural change.

Carbon prices alone, however, will not be high enough – at least for the next few decades – to prompt a large-scale roll-out of renewable energy, nor will they be sufficient to promote carbon capture and sequestration. Prices will be set for many years to come by cheaper sources of credit – energy efficiency and project-based mechanisms in the developing world. So a carbon price is an essential driver towards a lower carbon economy, but additional policy interventions will still be required.

Impact of the Current Financial Crisis

The road to a sustainable energy future is not without its speed bumps. Although total investment volume in 2008 declined only marginally over 2007, it was supported by a very strong first half. By the final quarter of the year, the volume of clean energy investment had dropped by over half from its peak at the end of 2007. Public market funding for clean energy businesses has decreased significantly, with valuations down by nearly 70% during the course of 2008. Venture capital and private equity investment held up reasonably well, but asset-based finance slowed markedly as the credit crunch ate into the availability of debt finance and the tax credits that have been driving the US wind boom.

The short-term challenge for the world's policy-makers is to maintain the extraordinary momentum of the clean energy industry in these difficult times. To do so, they must use all the tools at their disposal. An enormous monetary stimulus has already been applied through the drop in global interest rates.

On top of the monetary stimuli, policy-makers around the world are designing fiscal stimulus packages. As they do so, it is vital that every dollar should be made to multitask: it should support short term consumption and jobs, as well as building the long-term productive capacity of the economy, and at the same time moving us forward towards key long-term goals such as a sustainable energy system. Developing renewable energy technologies, rolling out a fully digital grid, properly insulating homes and offices, and educating a new generation of engineers, technicians and scientists should all be part of any fiscal stimulus programme.

The Need for Smart Policy

Even after the current crisis subsides, there will be a need for smart policy to support the shift to a clean energy infrastructure. The industry needs a well-designed set of support mechanisms – one that is tailored to each geography, and to the technological maturity of each sector. Sectors nearing maturity and competitiveness with fossil fuels need rate support as they close the gap; technologies that work in the lab but are too risky to scale up need support and finance to bridge the "Valley of Death"; sectors with longer-term technological promise need research funds.

Once policy-makers make incentives for clean energy a key element of their response to the current financial crisis, there will still be a need for further action. An entire ecosystem of supporting technology and service providers will be fundamental to the growth of a healthy clean energy sector – and this is inextricably linked to the ability of entrepreneurs and companies to create new businesses. One of the reasons that Europe consistently lags venture investment in clean energy in the US by a factor of five to seven is that the **conditions for venture investment** in Europe are less well-developed. Governments should also create markets for clean energy through **public procurement**. With central, regional and local government accounting for 35-45% of economic activity in all of the world's largest economies, public sector purchasing can be a powerful force. Clean energy use should be mandated in public procurement, which would create guaranteed markets for leading innovators in transport, heat and electricity.

Finally, policy-makers should enforce **energy efficiency standards**. Utilities and energy-intensive industries will respond to carbon prices and other price signals, but many individuals and businesses will simply not do so. As a result, there will always be a role for regulation to mandate certain changes in behaviour, such as appliance efficiency and standby power limits, corporate average fuel economy (CAFE) standards and building codes. They must also address the asymmetry between energy providers, who want their customers to use as much energy as possible, and consumers, who on the whole would prefer to use less.

But whichever policies are adopted, the overarching requirement is for policy **stability** – the impact of policy uncertainty on cost of capital must be better understood – and **simplicity**, so that the industry is not burdened with unnecessary bureaucratic costs. Poorly-designed, overlapping, intermittent, contradictory or overly-generous policies do more harm than good. Similarly investors need to understand the scale and nature of the investment opportunity presented by the world's one-time shift to low-carbon energy.

Conclusion

The need to shift to a low-carbon economy is stronger than ever. Clean energy technologies are becoming increasingly cost-competitive with fossil-based energy. A carbon price will eventually level the playing field, but in the meantime clean energy solutions require support from policy-makers.

Policy-makers need to build frameworks which enable corporations and investors to make good returns by squeezing carbon out of the world's economy. And investors need to understand the scale and nature of the investment opportunity presented by the world's one-time shift to low-carbon energy.

2009 is a critical year to bring these players together and start the transition toward a clean world energy infrastructure. The official UN negotiations will work on developing the overall framework for a follow on to the Kyoto Protocol by December of 2009. To complement and support this process, a platform should be created that connects policy makers (of the major economies in particular) with major investors and global energy corporations. A discussion, involving all these key players, can then take place during 2009 on how best to design the enablers identified in this report, in order to make the transition happen: a coalition of public-private expertise that designs the clean energy motor to drive the new framework forward.

2. Scale of the Challenge

A transformation in the world's energy infrastructure is required between now and 2030. The most recent data show CO_2 emissions and temperature trajectories tracking the pessimistic edge of the scenarios considered by the IPCC. To have a chance of limiting the average increase in global temperatures to 2°C, a level which an increasing number of experts already considers unsafe, we have to limit the concentration of greenhouse gases in the atmosphere to the equivalent of 450 parts per million of carbon dioxide by volume (450ppm CO_2e) – compared to 385ppm currently and 280ppm before the industrial revolution. Energy – principally electricity generation and transport fuels – accounts for more than 60% of the CO_2 emitted into the atmosphere each year. If we are to avoid the worst effects of climate change, therefore, we need to shift within the space of a few decades to a low-carbon energy infrastructure.

Figure 3. International Energy Agency World Energy Outlook 2008 – Highlights

The International Energy Agency's World Energy Outlook (WEO) 2008, published in November 2008, contains the most recent set of CO_2 forecasts. It is also a baseline used by many companies and institutions.
The key messages are as follows:

- The Reference scenario (equivalent to the status quo: no new policies supporting renewable energy) is compared to two scenarios: 550ppm and 450ppm CO_2e levels in the atmosphere. 450ppm is widely considered to be the maximum CO_2 concentration level required to avoid the worst effects of global warming by restricting temperature rises to 2°C. Both follow similar paths to an emissions plateau in 2020, after which the 450ppm assumes stronger and broader policy action.
- 77% of the emissions reductions (relative to the Reference scenario) will come from renewable energy and energy efficiency, with the balance from nuclear power and Carbon Capture and Sequestration (not considered a viable alternative in 2007).
- Energy demand in OECD countries under the Reference scenario will grow more slowly than predicted in 2007 (but faster for non-OECD countries) because of lower expected GDP growth combined with higher oil prices suppressing demand in developed countries.
- Renewable energy plays a larger role than in previous editions of the WEO, especially wind and solar power. Forecast renewable energy production in 2030, and consequently investments, was revised upwards from 2007 even in the base case Reference scenario.
- The 450ppm scenario depends on increasing spending on R&D now in order to develop the necessary advanced technologies
- Higher oil prices in the long-run (2030 estimate up from US$ 62/barrel in 2007 to US$ 122 in real 2008 terms), on the basis that lack of investment in existing fields will constrain supply and lead to a long-run rising oil price. This is positive for renewable energy, as it lowers the point at which renewable energy becomes competitive with conventional energy.

Source: IEA WEO 2008

The scale of investment required has been estimated by various different institutions, including the Stern Review, the International Energy Agency (IEA), the US's Energy Information Administration (EIA), McKinsey Global Institute and New Energy Finance. Their estimates of required investment vary considerably, not least because they use different definitions of the solution space, but all agree on one thing: that the sums involved are very substantial – trillions of dollars between now and 2030. In the long term, of course, the cost of doing nothing is even higher; the Stern Review estimated that inaction – adapting passively to climate change rather than acting now to mitigate it – will cost at least US$ 2.5 trillion, and will expose it to risks which are hard to quantify.

In 2005, the baseline year for most forecasts, energy-related CO_2 emissions accounted for 27,000 mega tonnes (Mt). By 2030, the IEA's latest baseline "Reference" scenario has emissions of 40,000Mt – an increase of just under 50%. This increase is not inevitable, however, particularly if action is taken quickly. The IEA has also published a "450ppm" scenario, in which CO_2 emissions are just 25,700Mt in 2030, a decrease of 5% from the 2005 figure (see Figure 3).

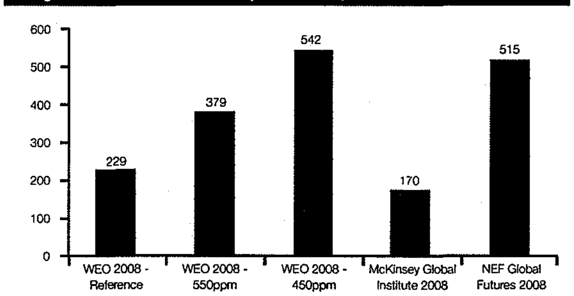
Estimates bold enough to look forward to 2050 are even more divergent. In its Energy Technology Perspectives scenarios – which include potential impacts of new technologies, the IEA has looked at a "Blue" scenario – in which just 14,000Mt are emitted by 2050 (half of 2005 CO_2 levels), compared with 62,000Mt in the Reference scenario.

These CO_2 emission reductions will be achieved by a combination of renewable energy and nuclear power, with energy efficiency playing a major role at all stages of the supply chain. Carbon capture and storage (CCS) contributes to almost every mitigation scenario.

Importantly, however, all the scenarios other than the business-as-usual Reference scenario, envisage a far higher proportion of renewable energy in the energy mix by 2030. Renewable energy accounts for as much as 46% of electricity generation in the more carbon-constrained scenarios, compared to 18% currently, and up to 23% of total primary energy demand (which includes transportation, heating etc). It is now widely accepted that renewable energy will provide a considerable contribution to the future energy mix. The questions now relate to the proportion of mainstream energy demand which will be met by renewable sources and, vitally, how much will the transition cost (see Figure 4).

The IEA's baseline Reference scenario sees cumulative energy investment of US$ 26.3 trillion between now and 2030. This includes cumulative renewable energy investment of US$ 5.5 trillion, of which US$ 3.3 trillion is for electricity generation – equivalent to US$ 229 billion a year for renewable energy, 60% of it for electricity generation. But this will result in an energy system which still contributes to 40,000Mt of global CO_2 emissions by 2030.

Figure 4: Annual Investment Required to 2030, US$ billions



Note: WEO 2008 covers investment in renewable energy generation and energy efficiency, with a New Energy Finance assumption that half the additional power investment required under the 550ppm and 450ppm scenarios is in renewable energy; McKinsey covers only energy efficiency investment; New Energy Finance Global Futures covers investment in renewable energy and energy efficiency technologies only.

Source: IEA WEO 2008, McKinsey, New Energy Finance

Even higher investment is needed to reduce emissions further. To reach emissions consistent with 550ppm CO_2e, additional investment of US$ 1.2 trillion is needed in generating capacity, and US$ 3 trillion in energy efficiency, nearly half of it in transport. To limit greenhouse gases to 450ppm CO_2e an additional US$ 3.6 trillion of generating capacity and significantly higher energy efficiency investment (US$ 5.7 trillion) is required from 2020 onwards.

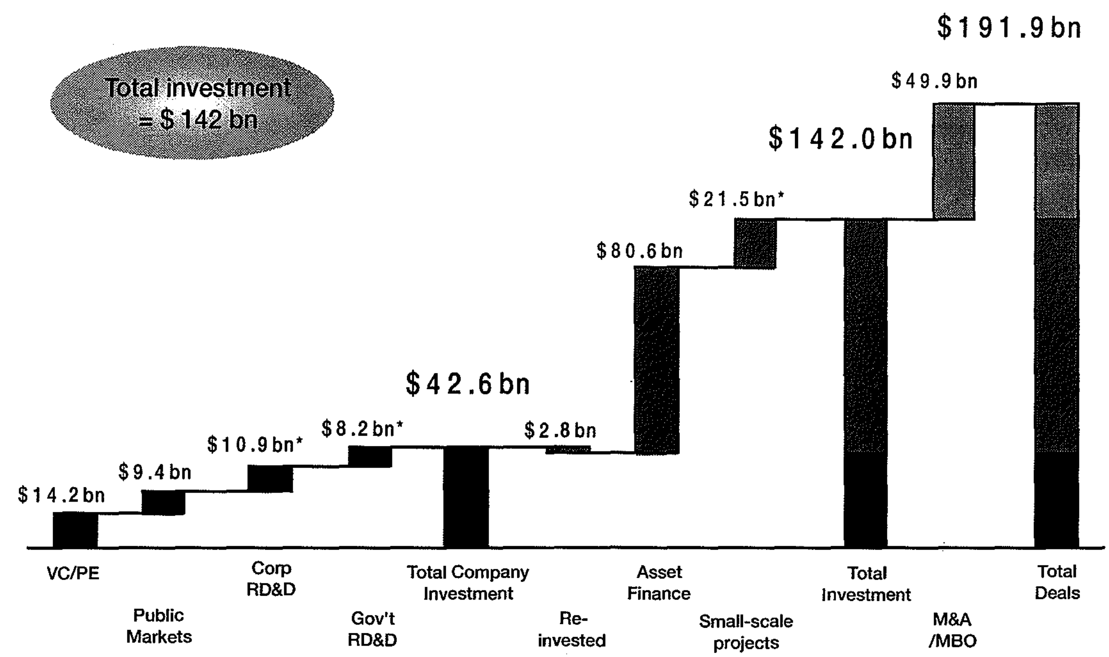
The role of energy efficiency in reducing energy demand cannot be underestimated. A recent McKinsey Global Institute report – How the World Should Invest in Energy Efficiency – estimates that energy efficiency alone could halve the projected growth in energy demand, delivering half the CO_2 emission cuts necessary for a 450ppm CO_2e outcome by 2030. This would involve exploiting US$ 170 billion of investment opportunities in energy efficiency that would produce an IRR of 17% or more. Not only does this compare favourably to the most obvious comparator, the IEA's 450ppm scenario, which requires additional annual investment in energy efficiency of US$ 238 billion, but the investment would only need to be made between 2009 and 2020, a mere 12 years, half the time horizon of most other forecasts, including those from the IEA.

3. Current Volume of Investment

The process of transition to a clean energy infrastructure has already begun, with a surge in investment from US$ 33 billion in 2004 to around US$ 150 billion in 2008. Investment in clean energy – defined here as investment in renewable energy and energy efficiency technology, but excluding nuclear power and large hydro – increased from US$ 33 billion to US$ 148 billion between 2004 and 2007 (see Figure 2), and now accounts for around 10% of global energy infrastructure spend. In electricity generation, the rapid expansion of sustainable energy has been even more striking, with 42GW of power generation capacity added in 2007, just under a quarter of the total 190GW of power generation capacity added worldwide.

Annual investment in renewable energy generation capacity is expected to top US$ 100 billion in 2008 – according to New Energy Finance's figures – and was growing at nearly 50% per year until the global financial crisis bit in the second half of the year. Prior to the crisis, New Energy Finance forecast investment in clean energy (including new energy efficiency technologies) would reach US$ 450 billion annually by 2012, rising to more than US$ 600 billion from 2020 (and probably even higher), indicating that the capital markets – at least before the credit crunch – were certainly capable of meeting the International Energy Agency's figures of US$ 380-540 billion required each year between 2008 and 2030.

Figure 5. Clean Energy Investment Types and Flows, 2008, US$ billions



New Energy Finance tracks deals across the financing continuum, from R&D funding and venture capital for technology and early-stage companies through to public market financing for projects and mature companies. Figures are adjusted to remove double counting. Investment categories used in this report are defined as follows:

Venture capital and private equity: all money invested by venture capital and private equity funds in the equity of companies developing renewable energy technology. Similar investment in companies setting up generating capacity through Special Purpose Vehicles is counted in the asset financing figure.

Public markets: all money invested in the equity of publicly quoted companies developing renewable energy technology and clean power generation. Investment in companies setting up generating capacity is included in the asset financing figure.

Asset financing: all money invested in renewable energy generation projects, whether from internal company balance sheets, from debt finance, or from equity finance. Excludes refinancings and short term construction loans.

Mergers and acquisitions: the value of existing equity purchased by new corporate buyers in companies developing renewable technology or operating renewable energy projects.

Source: New Energy Finance

The four-year surge from 2004-2007 in investment activity spanned all sectors, all geographies and all asset classes, and as a result the clean energy financing spectrum is well-developed, from very early stage investment in emerging technologies, right through to large established companies raising money on the public markets.

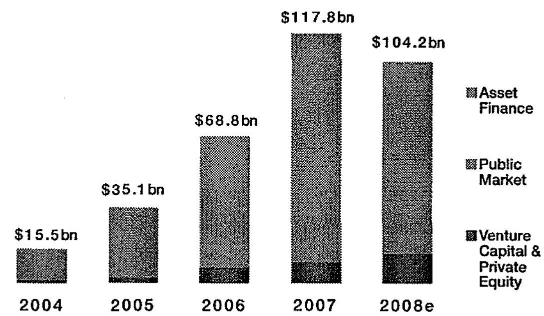
In 2008, new investment in clean energy is estimated to have reached US$ 142 billion worldwide (see Figure 5), down slightly from US$ 148 billion in 2007, but up nearly fivefold from US$ 33.4 billion in 2004. While the global financial crisis has slowed this growth, money is still flowing into clean energy. While the 2008 total is down only slightly from 2007, a strong start may disguise a much weaker second half of the year.

Of the 2008 investment, approximately 80%, or US$ 104 billion, was provided by third-party investors, such as Venture Capitalists, Private Equity providers, Asset Managers, Banks etc., to companies developing new technologies, manufacturing production equipment, and building new generation capacity across a range of clean energy sectors (see Figure 6). Most investment is in asset finance – building new renewable energy power generation projects and biofuels processing capacity – which is estimated at US$ 81 billion in 2008. Billions of dollars have been flowing in via the world's public markets, with US$ 23.4 billion raised in 2007, but only US$ 9.5 billion in 2008, as a consequence of the global financial crisis.

Wind is the most mature clean energy technology and accounted for more than a third of capacity investment (see Figure 7) – more than either nuclear or hydroelectric power. A total of 21GW of new wind capacity was added worldwide in 2007 – amounting to half of all new renewable energy capacity and over 11% of all new power generation capacity. In March 2008 the industry passed the milestone of 100GW installed capacity (for comparison, the United Kingdom has approximately 80GW of installed power generation capacity from all sources). An estimated 25GW of new capacity was added in 2008.

Solar energy is the fastest-growing sector. The development of large-scale solar projects propelled the sector into the limelight in 2007, when it attracted US$ 17.7 billion in project financing, nearly a quarter of all new investment – up 250% on the previous year. Solar is also the leading sector for venture capital investment, as investors back such emerging technologies as thin film (which uses less silicon and other non-silicon materials) and Solar Thermal Electricity Generation (STEG), whereby

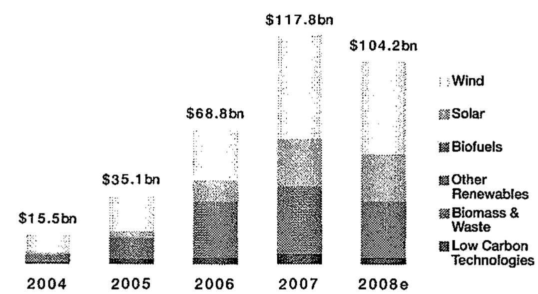
Figure 6. Clean Energy Investment by Asset Class, 2004-2008e, US$ billions



Note: Totals are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database. They exclude R&D and Small Projects.

Source: New Energy Finance

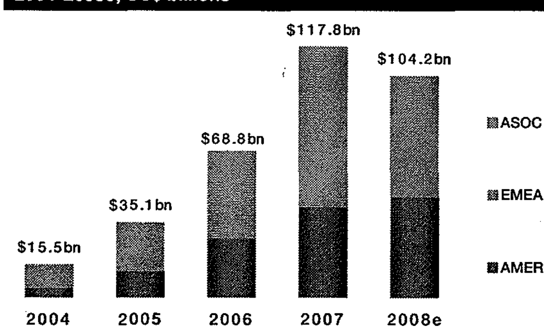
Figure 7. Clean Energy Investment by Sector, 2004-2008e, US$ billions



Note: Totals are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database. They exclude R&D and Small Projects. Other Renewalbes includes geothermal and mini-hydro; Low Carbon Technologies includes energy efficiency, fuel cells, power storage.

Source: New Energy Finance

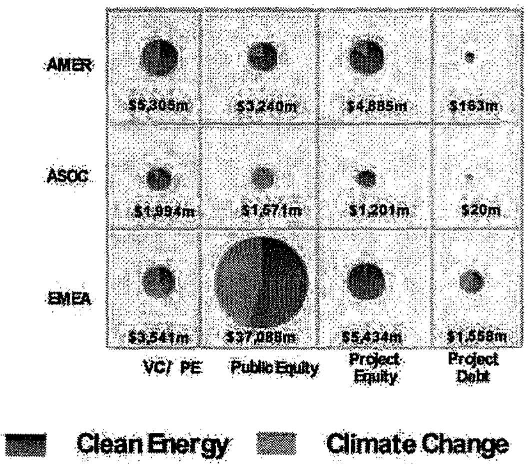
Figure 8. Clean Energy Investment by Geography, 2004-2008e, US$ billions



Note: Totals are extrapolated values based on disclosed deals from the New Energy Finance Industry Intelligence Database. They do not include R&D or Small Projects, which is why the total in this chart is lower than the headline total new investment shown in other charts. ASOC = Asia Oceania region; EMEA = Europe Middle East Africa region; AMER = Americas region.

Source: New Energy Finance

Figure 9. Clean Energy and Climate Change Funds by Region, 2008



Note: Data as of October 2008; Data refers to total assets managed

Source: New Energy Finance

the heat of the sun is concentrated with mirrors to produce steam and drive a conventional turbine. Total solar investment in 2008 is estimated at US$ 26 billion, a 10% increase on 2007.

The past few years have seen an explosion of interest in clean energy by venture investors, attracted by the size of the markets that will be created. New Energy Finance has identified over 1,500 separate venture and private equity groups, all searching for the clean energy equivalent of Cisco, Dell, Amazon or Google. Indeed, Google itself is one of the searchers, with a strong commitment to clean energy.

It remains to be seen how many of these venture players will retain their interest after the energy price crashes. Having said that, venture and private equity investment in the sector has continued throughout the financial crisis, with an estimated US$ 14 billion of new investment (excluding buyouts) in 2008. As well as the solar sector, investors have been looking for winners among the next generation of technologies, from cellulosic and algae-based biofuels – which bypass the conflict between food and fuel – through to energy storage and digital energy management. Companies working on energy efficiency have been attracting record investment, especially from earlier-stage investors. The period 2003 to 2005 saw a flurry of venture activity in the hydrogen and fuel cell sector.

Investment in clean energy has not only increased over the past few years, but has also diversified geographically (see Figure 8). As recently as five years ago, clean energy meant wind, mostly in Denmark, Germany and Spain. Since then renewable capacity rollout has shifted away from Europe and towards China and the US. Developing (non-OECD) countries attracted 23% (US$ 26 billion) of asset financing in 2007, compared to just 13% (US$ 1.8 billion) in 2004, although the bulk of this went to the fast-growing economies of China, India and Brazil. India and China in particular are determined to become clean energy powerhouses. By 2007, investment in clean generation capacity in China – excluding large hydro projects such as the Three Gorges dam – had soared to US$ 10.8 billion.

Finally, the past few years have seen another trend of significance in the financing of clean energy – the provision of investment vehicles for those not able or willing to make their own direct investments. In 2004, there were only 10 quoted equity funds targeting the sector, almost all of them run by specialist companies such as Triodos, Sustainable Asset Management and Impax. By the end of 2007, the lay investor had the option of more than 30 funds, several managed by high-street names such as Deutsche Bank, ABN Amro, HSBC or Barclays. By October 2008 these funds had over US$ 42 billion in assets under management (see Figure 9). A number of Exchange Traded Funds had also been launched, including the Powershares Global Clean Energy Fund, which tracks the WilderHill New Energy Global Innovation Index (NEX) and soon grew to have over US$ 200m in assets under management.

4. Investment Performance

Over the past few years, prior to the recent turmoil in the global financial markets, investors made good returns from clean energy investments at all stages of the value chain. While the exceptional gains of the past few years may have declined during 2008, the sector as a whole has fared better than any major benchmark over the past five years.

4.1 Public Markets

The WilderHill New Energy Global Innovation Index (ticker symbol NEX) tracks the performance of around 90 leading clean energy companies, spanning different sectors, geographies and business models.

Over the period from the beginning of 2003 to the end of 2007, the NEX rose from its index value of 100 to a peak of 549.08, a compound annual growth rate of over 40%. 2007 was a particularly high-octane year, logging an increase of 57.9%, and the index defied gravity for the first three quarters of 2008, before succumbing to the credit crisis and ending the year at 178 (see Figure 10).

Back-testing suggests a fairly close correlation existed between the NEX and NASDAQ between 2000 and 2003, when many renewable energy stocks were seen as technology plays. However, this changed as clean energy came into its own as an investment sector against a background of higher energy prices, environmental and geopolitical concerns. Now the NEX correlates most closely with the oil price (see Figure 11). As the oil price has fallen in recent months, so has the NEX, although December 2008 saw further falls in oil prices along with a recovery in the NEX.

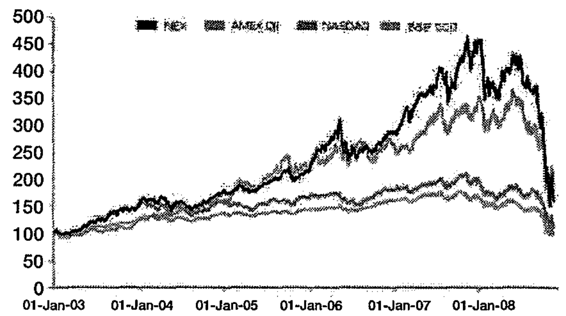
Indeed, although historically clean energy stocks have been more volatile than those from other sectors, their returns have been consistently higher, making them an attractive investment proposition on a risk-adjusted basis despite their recent history (see Figure 12). Even after its tumultuous 2008, the NEX remained up 75% on six years ago – an annual return of 9.8%, unmatched by any of the major stock market indices.

4.2 Venture Capital and Private Equity

On the venture capital and private equity side, some spectacular returns were achieved during the period 2004 to 2007.

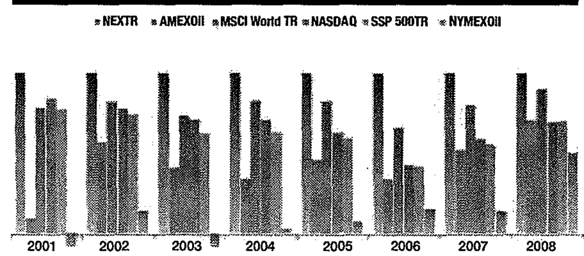
For private equity players, one of the most successful strategies during this period was to identify clean energy companies which had been struggling to commercialize their products or services during the period of low energy prices, but which were now experiencing soaring demand. Allianz Private Equity and Apax Partners shared

Figure 10. Performance of NEX vs Major Indices, 2003 to 2008



Source: New Energy Finance, Bloomberg

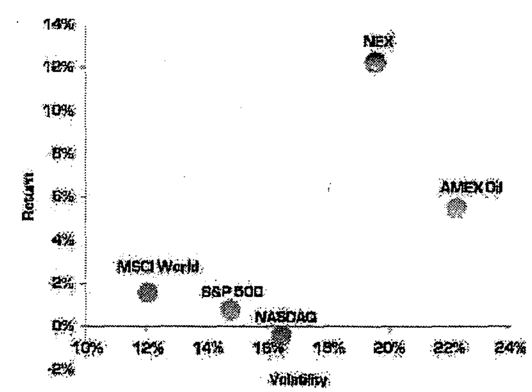
Figure 11. Correlation of NEX to Indices and Oil, 2003 to 2008



Note: Correlation measures how close the relationship between the NEX and other indices is. The higher the correlation, the closer the relationship. Negative correlation indicates a contrary relationship (when one goes up, the other goes down).
Correlation at 2 December 2008. Nymex Oil refers to oil futures; Amex Oil is an oil company index

Source: New Energy Finance

Figure 12. NEX vs. AMEX Oil, NASDAQ and S&P 500, Sep 2005 – Sep 2008



Note: Returns are over 3 years, annualized so they represent the compound annual return. Volatility is averaged over the same 3 year period.

Source: New Energy Finance

the private equity deal of the year in 2006. They bought Hansen Transmissions, a leading provider of gearboxes for wind turbines for € 132m, and 22 months later they were able to sell it for € 465m to India's Suzlon Energy, then the world's most valuable turbine manufacturer, recording an IRR of 101% on their investment. Other very successful deals of this nature included an investment made by Goldman Sachs in Zilkha Renewables (later renamed Horizon Wind Energy), which they were subsequently able to sell to Energias de Portugal at a substantially increased value.

Meanwhile in venture capital, investors in clean technologies in Europe and the US were on track to achieve excellent returns on their investments up to mid-2008, according to the third annual European Clean Energy Venture Returns Analysis (ECEVRA), completed by New Energy Finance in collaboration with the European Energy Venture Fair.

The study, which is based on confidential returns by investors at the end of H1 2008, covered 302 clean technology portfolio companies, representing € 1.77 billion of venture capital invested in clean technology since 1997. Of these, 26 have so far resulted in public listing and 32 have been exited or partially exited via trade sale. The success rate to date has been reasonably high with a pooled gross IRR (at the portfolio company level, not the fund level) of over 60%, based on the limited number of exits and with only 23 companies being liquidated or written off at the time of the study,. These exceptional returns, were driven by the outstanding success of a small number of early investments in the solar sector – Q-Cells and REC in particular. Without these, the pooled return was closer to 14%. As of mid-2008 there had been relatively few down-rounds (subsequent venture rounds at reduced valuations), but it is a very young sample with relatively few exits to date.

Of course these returns relate to an extraordinary period in history – combining a period of extreme interest in all things green with historically cheap access to debt. There is no doubt that the next few years will be much harder for venture and private equity investors in clean energy. Any downturn in venture capital will not, however, be confined to the clean energy sector. According to quarterly analysis by Thomson Reuters and the National Venture Capital Association (NVCA) of nearly 2,000 US investors, venture capital performance dropped sharply in the second quarter of 2008, although venture capital returns still exceeded public market indices (S&P and NASDAQ). Venture exits in general have also fallen sharply. The first three quarters of 2008 saw only six IPOs of venture-backed companies, representing the lowest volume for the first three quarters of the year since 1977. Meanwhile for those venture capital and private equity investors who have raised their funds but kept their powder dry, this looks like a good point in a notoriously cyclical asset class to be making investments.

4.3 Asset Finance

The bulk of new investment in the clean energy sector (approximately 80%) is in asset finance – to fund the building of wind farms, geothermal power plants, biofuels refineries and the like. A large number of different financing structures have been used: fairly standard project finance structures may account for the bulk of deals, but utilities have funded much new capacity on their balance sheets. In the US, tax equity tends to take the place of debt; lease finance, export finance and multilateral agencies such as development banks also play a major role.

Typical project equity returns range from the very low – perhaps where investors are driven by regulatory or charitable requirements – to extremely attractive. Early wind projects in Italy, for instance, were able to generate equity returns of 20-30% because of high electricity and Green Certificate prices, allied with good wind resources. However, returns were later pushed down as there were fewer sites to choose from. Indeed this trend has been replicated in all major wind markets, with later projects often located in lower wind speed areas, providing their investors with lower returns. This has encouraged investors to seek new markets to hit target returns, including Latin America (especially Chile) and Eastern Europe (particularly Poland, Romania and most recently Bulgaria). It has also meant that utilities, whose target rate of return is lower than that of private equity investors, have become the leading proponents of greenfield wind farms.

Equity investors in clean energy assets are typically divided between three camps: the developer who identifies the clean energy resource and puts the project together; equity sponsors who help to fund the project through the construction phase but aim to sell the completed asset; and those primarily investing in operating assets, who wish to avoid development risks, specializing instead in the management of existing assets. Naturally there is cross-over between these classes of investor, where developers have sufficient capital to do without equity sponsors and retain their portfolio of developed wind-farms, but as capital has become more constrained this is becoming the exception, rather than the norm.

The very rapid recent pace of growth in the wind industry (25% compound annual growth in installation activity) has afforded plentiful opportunities for financial investors. Equity sponsors of projects under development are exposed to significant development, financing, turbine supply, and interest rate risks. They have, however, succeeded in achieving strong returns. Good projects by strong developers are able to sustain higher effective interest rates and lower leverage, and so have remained financeable throughout 2008.
Yields from existing wind projects vary depending on local tariffs and/or tax incentives, the wind regime, maintenance costs, and financing structure. Ultimately returns to investors purchasing operating wind assets will depend on the entry price. With a significant number of portfolios being put on the market by distressed sellers, and the promise of cheaper debt in coming years, 2009 looks like it may be a good year for bargain-hunters.

Meanwhile in the solar sector, the cost of electricity from photovoltaic cells is due to plummet in 2009. The second issue of the quarterly New Energy Finance Solar Silicon and Wafer Price Index, which was published in December 2008, forecasts average silicon contract prices falling by over 30% during 2009. With thin-film PV module manufacturing costs approaching the US$ 1/Watt mark, crystalline silicon-based PV will come under severe competition for larger projects, resulting in margins shrinking throughout the silicon value chain, and substantially lower prices for consumer.

New Energy Finance analysis, based on the historic cost experience curve, suggests that current silicon-based solar module prices of US$ 4/Watt could drop to US$ 2.60/Watt by the end of 2009, a reduction of 35%, before leading manufacturers started making losses on marginal sales. For a ground-mounted plant in a region with good insolation, and based on a 6% real cost of capital, this could translate into an unsubsidized generation cost of US$ 0.17/kWh for crystalline silicon – competitive with daytime peak retail electricity prices in many parts of the world, but not yet with wholesale prices.

Figure 13. Investment and Energy Poverty

According to the UN, over 2 billion people lack access to modern fuels and 1.6 billion lack access to electricity. Renewable energy can play a major role in addressing energy poverty, but the traditional finance sector is ill-equipped to finance their deployment.
A wide range of renewable energy technologies offer promise in providing energy services to the poor in the developing world – including micro-digesters to produce gas for cooking and heating, solar water heaters and cookers, advanced biomass combustion, and of course distributed electricity generation from photovoltaic and other sources. Indeed, where no grid or fuel distribution infrastructure has yet been built, these solutions will often be cheaper than traditional fossil-based sources of energy. However, their provision will require the investment of hundreds of billions of dollars over the coming decades. Traditionally, governments, development agencies and multilateral lenders such as the World Bank, Asian Development Bank, and the EBRD have provided finance focusing on large-scale projects. Effectively remedying energy poverty will require a very large number of small projects, requiring microfinance approaches that are beyond the capabilities of most mainstream investors. In addition, local entrepreneurs often need substantial support in developing technologies and business models to deliver solutions.
A number of organizations are working on innovative ways of using microfinance to provide clean energy in developing countries. An in-depth discussion of these financial pioneers is beyond the scope of this report, but they include the following:
- Acumen Fund www.acumenfund.org
- D-Light Design www.dlightdesign.com
- E+Co www.eandco.net
- GEXSI www.gexsi.org
- Global Village Energy Partnership www.gvep.org
- Grameen Shakti Bank www.gshakti.org
- Green Microfinance www.greenmicrofinance.org
- Solar Electric Light Fund www.self.org

A survey of a further selection of providers has been undertaken by the SEEP Network and can be found here: http://www.seepnetwork.org

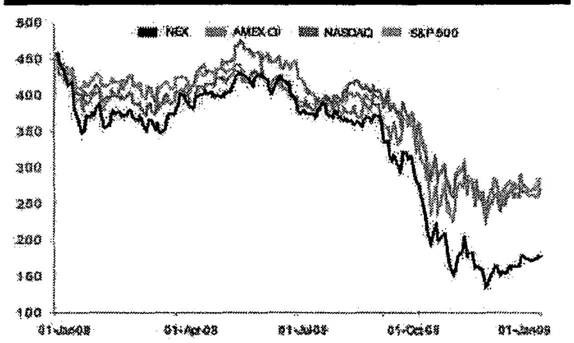
Source: IEA WEO 2008

5. Impact of the Global Financial Crisis

The global financial crisis of 2008, and the recession that is following in its wake, represents a serious threat to the clean energy sector. Short-term energy and carbon prices have fallen, making clean energy less competitive in immediate financial terms. At the same time risk has been re-priced, and finance is much harder to come by. The crisis may, however, also represent something of opportunity: as policy-makers take decisive action to refuel their economies, they are at least talking about ensuring the resulting fiscal and monetary stimuli benefit the clean energy sector. Beyond that, it remains to be seen whether the crisis will shake policy-makers' determination to shift to low-carbon energy and force embattled voters to take painful action to limit greenhouse gas emissions.

Clean energy investment held up well during the early phase of the credit crunch, as did the valuations of publicly-quoted clean energy companies, only to be very hard hit during the closing months of 2008.

Figure 14. Performance of NEX vs Major Indices, 2008



Note: Index Values as of 31 December 2008; AMEX Oil, NASDAQ and S&P 500 rebased to 455.19 on 31 Dec 2007

Source: New Energy Finance, Bloomberg

The NEX index defied gravity for the first three quarters of 2008, trading mainly in the 350 to 450 range. The final quarter of 2008, however, saw the index collapse, touching a low of 135.15 in late November, a level not seen since September 2003 – before the ratification of the Kyoto Protocol, before Hurricane Katrina and President Bush's statement that the US was "addicted" to oil, before the publication of the Stern Review, before the premiere of the Inconvenient Truth.
Since that low, however, the NEX index has bounced back, ending the year at a slightly more respectable 178 – perhaps in recognition that the sector's sell-off had been overdone, perhaps as opportunistic investors began to pick up bargains, and perhaps on hope that the election of President Obama would create a floor through which the sector would not fall (see Figure 14).

There are three reasons why the sector was hit so hard. First, with energy prices collapsing by 70%, the sector was bound to suffer – these are, after all energy stocks. Second, investors were getting rid of stocks with any sort of technology or execution risk, in favour of longer-established businesses. Third, in an era of sharply constrained credit, investors penalized companies with high capital requirements – even the more established, asset-based clean energy companies, which bear no technology risk, being high-growth are capital-hungry.

The collapse in valuations of clean energy companies effectively shut the door to further fund-raising in the public markets. New financings – IPOs, secondary offerings and convertible issues – dropped by 60%

Table 1. Global Clean Energy Investment, 2007-2008: US$ billion

Asset Class	2007	2008e	Change
Venture Capital/Private Equity	US$ 9.8 billion	US$ 14.2 billion	45%
Public Markets	US$ 23.4 billion	US$ 9.4 billion	-60% (minus)
Asset Finance	US$ 84.5 billion	US$ 80.6 billion	-5% (minus)
Total	**US$ 117.7 billion**	**US$ 104.2 billion**	**11%**

Note: 2008 estimates are New Energy Finance preview figures, published in October 2008

Source: New Energy Finance

between 2007 and 2008 to US$ 9.4 billion (see Table 1), mainly because of turbulent market conditions and lower valuations. 2007's total was boosted by Iberenova's US$ 6.6 billion IPO, the fourth largest in the world in any sector.

Venture capital and private equity to a certain extent stepped in where the public markets stepped out during 2008. New investment – i.e. excluding buyouts – is estimated to have reached US$ 14.2 billion in 2008, 45% higher than a year earlier. Venture capitalists, those that have already raised funds and now need to put them to work, have continued to invest, particularly in the solar and digital power sectors. In the wake of decreased leverage, there is evidence that some private equity players have preferred to invest expansion capital with modest leverage rather than return money to their limited partners. Meanwhile, anecdote suggests that valuations have come down, though not quite to the extent of public market valuations, making this a good time to invest for those that have funds available.

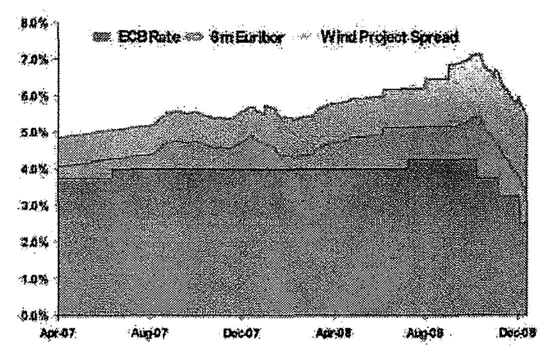
The most serious impact of the credit crunch has been felt in asset finance. New build investment volumes fell steadily throughout 2008, from a peak of US$ 26.7 billion in Q4 2007. They are forecast to total US$ 80.6 billion in 2008, a fall of only 5% on the year before, but the true scale of the drop in investment is masked by investment in the first half which was much higher than in the same period in 2007. By the final quarter of the year, investment volume was down over 30% on the peak. Not only has it become harder for clean energy project developers to access capital, but borrowing costs have risen sharply. Even though underlying central bank interest rates have fallen around the world, interbank lending rates have risen and project debt spreads have widened: in the European wind industry, for example, borrowing margins have more than doubled from 80 basis points over Euribor in the second half of 2007 to 170 basis points in 2008 (see Figure 15).

Even during the darkest weeks of October and November 2008, investment deals continued to close, including a rights issue by Brazilian bioethanol leader Cosan, which raised US$ 412m, and Chinese wind turbine manufacturer Dongfang Electric Corporation, which raised US$ 195m in a secondary offering. In addition, over 80 VC and PE deals were completed in Q4 2008.

A repeat of the collapse in investment in clean energy which followed in the wake of previous spikes in energy prices in the 1970s and 1980s, therefore, does not look likely. For one thing, there is a web of policy in place around the world which supports a mandated level of activity far in excess of previous levels. Secondly, no serious commentator expects oil prices to revert to the US$ 25 per barrel median price (in 2008 money) which prevailed throughout the 1990s. Growing demand for oil – much of it fuelled by the rising middle classes in China and India – is demanding the exploitation of ever more expensive sources of supply – deeper offshore fields, shale oils and tar sands – driving up the cost of marginal production.

There is no question that the short-term priority for the world's policy-makers is to do whatever is necessary to prevent the effects of the financial crisis turning from a recession to a depression. The good news for clean

Figure 15. Debt spread chart for 200MW European area wind farm, 2007-2008



Note: Data as of 13 December 2008

Source: New Energy Finance, Bloomberg

energy investors is that supporting the sector is seen by the leaders of many of the world's major economies as consistent with achieving this goal. As they address the urgent problems and then the longer-term structural weaknesses of their economies, the clean energy sector stands to benefit as follows:

1. **Monetary stimulus.** An enormous monetary stimulus has already been applied in every major economy of the world – central bank rates have dropped to levels not seen for half a century. At the time of writing, this wall of cheap debt has not yet worked its way through the system, as banks steward their capital in fear of the levels of defaults which will emerge as the recession bites. However, at some point a flood of cheap money will begin to flow, and when it does, clean energy infrastructure – safe projects with reliable yields – will be among the first to benefit. Renewable energy projects generally have higher up-front costs but lower

or no fuel costs, making them more than averagely sensitive to periods of higher interest rates or credit risk aversion – and more than averagely responsive as interest rates fall.

2. **Fiscal stimulus.** Around the world debate is raging, not about whether fiscal stimulus is needed, but how much and what sort. Policy-makers are trying to ensure that any fiscal stimulus multitasks by supporting short term consumption and jobs and building the long-term productive capacity of the economy, as well as moving us along in achieving our long-term goal of a sustainable energy system. The development of clean energy technologies, rolling out a fully digital grid, properly insulating homes and offices, and educating a new generation of engineers, technicians and scientists meet all of these criteria and could be part of many fiscal stimulus programmes.

3. **Deficit reduction.** Policy-makers are likely to look for sources of tax which are not only substantial, but at the same time encourage the move towards a low-carbon economy. And that means the likely dismantling of any fiscal support for fossil fuels – fuel subsidies, research grants, exploration concession waivers, investment tax holidays, accelerated depreciation, export guarantees and soft loans. Then we could see increasing energy taxes, a dramatic reduction of fuel subsidies in the developing world, and either a carbon taxes or cap-and-trade schemes with auctioning of permits.

The position of US president-elect Barack Obama is of particular interest in this context. During his campaign, he stated that "there is no better potential driver that pervades all aspects of our economy than a new energy economy ... that's going to be my No. 1 priority when I get into office." As well as supporting the extension to the Production Tax Credits and Investment Tax Credits, so instrumental in the development of the US wind and solar sectors, he has indicated his support for a federal Renewable Portfolio Standard (the minimum proportion of renewable power in the electricity mix) of 25% by 2020. He has also committed to spending US$ 150 billion on clean energy over the next 10 years.

Since his election, President-Elect Obama has galvanized the world's carbon negotiators by restating his commitment to provide leadership on the issue of greenhouse gas emissions. By the time this report appears, President Obama's inauguration will have taken place, and he may have outlined both the nature of the fiscal stimulus that will be applied to the US economy in 2009, and his policy towards clean energy.

In summary, while the global financial crisis has certainly brought the clean energy sector down to earth with a bump, the fundamental drivers – climate change, energy security, fossil fuel prices and scarcity – remain strong. With continued government support through the current financial crisis, the sector will likely see a return to its long term growth trend in the near future.

6. Eight Key Renewable Energy Sectors

No-one can predict with any certainty what the energy mix will look like in 2030, let alone 2050. Fossil fuel generation will undoubtedly still be a substantial part of the equation. However, it is clear that any future low-carbon energy infrastructure will have to include a significant proportion of energy generated from renewable sources – most scenarios showing the proportion of primary energy having to reach 40-50% by 2050. Some of the leading technology contenders are emerging and, in some cases have begun to build significant experience.

In this section, we highlight eight renewable energy technologies which look particularly promising in terms of two factors: abatement potential and current state of competitiveness. In the next section we will look at some of the other technologies – principally around the digital/smart grid, energy efficiency, power storage and carbon capture and sequestration – which will be required if low carbon energy is to fulfil its full potential within the future energy mix.

1. **Onshore Wind.** The most mature of the renewable energy sectors, the onshore wind industry saw 21GW built in 2007, bringing installed capacity to over 100GW. In Germany, Spain and Denmark wind power now supplies 3%, 11% and 19% respectively of total electricity production during the course of the year, and in Denmark up to 43% of the country's electricity demand at times of peak wind supply. Electricity from onshore wind can be generated at prices of 9-13 c/kWh, making it only 32% more expensive than natural gas CCGT, even in the absence of a carbon price.

2. **Offshore Wind.** When the best sites for onshore wind have been snapped up, the next place to look for large quantities of renewable energy is offshore. Offshore wind offers enormous potential, with stronger more predictable winds and almost unlimited space for turbines. Planning permission can be easier to obtain than onshore, farms can be built at scales impossible on land, and the availability of space is almost unlimited if deep waters are mastered. At present, the cost of electricity from offshore wind is high – around 16-21 c/kWh – but this will come down rapidly as more project experience is gained.

3. **Solar Photovoltaic Power.** Photovoltaic (PV) technology has made very rapid strides in the past four years, in terms of reducing the cost of crystalline silicon (its main component) and commercializing thin film technology, with investment volume growing to US$ 50 billion in 2007-2008. Although there has been a bottleneck in the production of solar-grade silicon, new capacity is coming on line and costs are set to drop rapidly from US$ 4/W to US$ 2.60/W by the end of 2009, making unsubsidized solar PV generation costs comparable with daytime peak retail electricity prices in many sunny parts of the world.

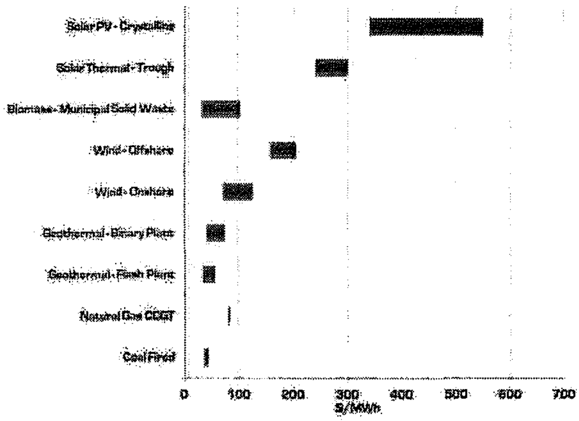
4. **Solar Thermal Electricity Generation.** While PV is ideal for smaller projects and integrated into buildings, the technology of choice for big solar plants in the world's deserts looks set to be Solar Thermal Electricity Generation (STEG): concentrating the heat of the sun to generate steam, which can be used in conventional and highly efficient turbines. There are relatively few projects up and running yet, but with costs already in the 24-30 c/kWh range, this technology is shaping up to be a part of the solution in the sunniest parts of the world.

5. **Municipal Solid Waste-to-Energy (MSW).** The use of municipal solid waste to generate energy is increasing, led by the EU countries. Waste has traditionally been deposited in landfill sites, a practice which is becoming increasingly expensive and constrained by shortage of sites. Landfill also creates methane, a powerful greenhouse gas. Waste that cannot be recycled, however, can be used to generate electricity by a variety of technologies at costs starting at 3 to 10 c/kWh. Government support for the development of MSW plants is increasing, for example through the Private Finance Initiative (PFI) in the United Kingdom. The US MSW sector is also seeing a resurgence, with specialist operators planning to build several new plants.

6. **Sugar-based Ethanol.** The period 2004-2006 saw US investment in biofuels soar, with investors pouring US$ 9.2 billion into the sector. But most of this flowed into corn-based ethanol, which is more expensive to produce than sugar-based ethanol, subject to volatile prices and controversial because its feedstock is a food staple around the world. By contrast, Brazilian sugar cane-based ethanol is competitive with oil at US$ 40 per barrel; it grows well in many southern hemisphere countries (and far from the Amazon); and there is no shortage of land to increase production substantially without jeopardizing food production.

7. **Cellulosic and Next Generation Biofuels.** The argument over food vs fuel is an emotive one. In most regions, there is sufficient land to increase biofuels production from the current 1% of transport fuel to 3% or even 5% without impacting on food availability (as long as we can quickly return to increasing annual agricultural productivity). But after that the only way to

Figure 16. Clean Energy and Traditional Technologies – Range of Levelized Costs of Energy, December 2008, US$/MWh



Note: Levelized Cost of Energy (LCOE) allows different energy generation technologies to be compared, taking into account their cost of production and generation efficiency. Figures indicate the required range of generation price for each clean energy technology to be competitive. Levelized costs exclude any subsidies. LCOE analysis assumes an internal hurdle/return rate of 10%, which is used to derive generation costs. Base case assumptions: interest rate = 2.5%; Fuel price (2009): Coal = US$ 115.29/tonne, Natural Gas = US$ 11.49/MMBtu; Carbon price (2009) = US$ 28.11/tonne.

Source: New Energy Finance

increase production of biofuels will be to source feedstock that does not compete with food. Luckily, the cost of producing biofuels from agricultural waste through cellulosic conversion and algae is coming down rapidly, and the future fuel system is likely to include a proportion of fuels from these sources. Future technologies could include artificial photosynthesis and synthetic genomics.

8. **Geothermal.** Geothermal power is particularly attractive as a renewable energy source because it can be used as predictable base-load power in a way that wind and solar power cannot be. Until now, geothermal power has been used only in limited regions, but a raft of new approaches has helped make it economically viable across a wider area. In addition, all countries can exploit geothermal resources for ground source heat pumps or district heating, if not for large-scale electricity generation.

Table 2. Sensitivity of Power Costs to Changes in Inputs

	Base case power generation cost (US$/MWh) and (comparative ranking)	Interest rate -300 bp (% change)	Fuel prices +20% (% change)	Carbon prices +20% (% change)	Potential cost in low interest, high fuel and carbon cost scenario this excludes any impact of scale or experience curve! (US$/MWh) and (revised comparative ranking)
Coal Fired	40.6 (1)	-7.1%	+6%	+45%	58.1 (4)
Natural Gas CCGT	82.0 (5)	-1.3%	+16%	+14%	104.8 (6)
Geothermal – Flash Plant	44.3 (2)	-4.6%	-	-	42.3 (1)
Geothermal – Binary Plant	58.0 (3)	-5.1%	-	-	55.0 (3)
Wind – Onshore	108.2 (6)	-10.4%	-	-	88.8 (5)
Wind – Offshore	181.8 (7)	-5.5%	-	-	171.8 (7)
Biomass – Municipal Solid Waste	67.5 (4)	-12.1%	-	-	54.8 (2)
Solar Thermal – Trough	270.9 (8)	-7.7%	-	-	249.9 (8)
Solar PV – Crystalline	445.7 (9)	-8.1%	-	-	409.5 (9)

Note: Levelized Cost of Energy (LCOE) allows different energy generation technologies to be compared, taking into account their cost of production and generation efficiency. Levelized costs exclude subsidies. LCOE analysis assumes an internal hurdle/return rate of 10%, which is used to derive generation costs. LCOE analysis assumes an internal hurdle/return rate of 10%, which is used to derive generation costs. Base case assumptions: interest rate = 2.5%; Fuel price (2009): Coal = US$ 115.29/tonne; Natural Gas = US$ 11.49/MMBtu; Carbon price (2009) = US$ 28.11/tonne

Source: New Energy Finance

Table 3. Summary Table of Target Sectors

	Installed Capacity Worldwide, 2008	Relative Scale by 2030	Market Readiness/ Levelized Cost of Energy	Technology Gaps	Potential Bottlenecks	Policy Requirement
1. Onshore wind	103.5GW	More than 1,000GW	US$ 89-126/MWh	• Existing technology adequate, drive train improvements required to increase reliability and decrease costs • Ever-larger turbines • Power storage (to reduce impact of intermittency)	• Short term: capital availability • Longer term: bearing, gearbox and blade supply chain • Weakness of electricity grid • Slowness of planning applications	• Stable implementation of existing policies • Modest rate support in the form of Renewable Portfolio Standard, Feed-in Tariff or Green Certificates • Accelerated planning processes • Incentives/regulation to require integration and remove grid bottlenecks
2. Offshore wind	1.5GW	100GWs	US$ 158-205/MWh	• Reliability of offshore turbines still a key concern • New dedicated marinized technology at larger scale being rolled out over next 5 years	• Turbine supply resulting from low margins on sale compared to onshore turbines	• Continued, stable support in Germany and the United Kingdom • Attractive tax treatment of RD&D • Incentives/funding for grid development • Accelerated planning processes
3. Solar PV	13.3GW	10GWs	Currently extremely uneconomical (US$ 341-549/ MWh) but with potential to halve in next 2 years	• Continued scale-up of entire crystalline silicon supply chain; process engineering to reduce costs • Mass manufacture of scalable, high-efficiency thin film on flexible substrates • Jump to next generation of super-efficient cells	• Capital • Access to transmission grid • Refined silicon, formerly bottleneck about to go into oversupply	• Substantial support, long-term but declining over time, in the form of investment tax credits • Mandatory net metering by utilities • Attractive tax treatment of R&D • Public research funds
4. Solar thermal	438MW	10GWs	Uneconomical (US$ 241-299/ MWh) with some reduction potential	• Proof of concept for most up-and-coming technologies	• Availability of steam turbines • Links to transmission grid • Permitting	• Rate support in the form of Renewable Portfolio Standard, Feed-in Tariff or Green Certificates • Clear direction on permitting for large projects which cannot currently get planning permission in the US • Attractive tax treatment of RD&D
5. Sugar-based ethanol	70 billion litres per annum	250+ billion litres per annum	Competitive with oil at around US$ 45 per barrel	• Mass adoption of efficient cogeneration equipment • Ability to use efficiently all cane residues • Biotechnology for longer term/geographical viability: transgenic cane • Adoption of flexible fuel vehicles in different countries • Transfer of technology to different sugar-producing countries	• Import tariffs/corn ethanol subsidies • Lack of hedging instruments/no liquid futures market or long term contracts • Logistics to keep costs low and increase export capability: transport, storage and port facilities • Price of oil below US$ 50 for external market	• Definition of sustainability criteria and international standards • End of import tariffs in EU, US, Japan • Adoption of blend targets • Brazil: legislation to allow for use of transgenic cane
6. Cellulosic and Next generation biofuels	10 million litres per annum	100+ billion litres per annum	n/a	• Selection or development of economically optimal feedstocks • Lower process cost using enzymes, bacteria and fungi • Development of algae-based biofuels	• Producing of feedstock to quantity and quality required • Cost of feedstock collection/delivery to refineries • Ability of existing infrastructure to cope with next generation biofuels volume	• Capital support from governments for demonstration-scale projects • Blending subsidies to ensure demand – especially during periods of low oil prices • Incentives for farmers to produce energy crops • Attractive tax treatment of RD&D
7. Geothermal	10GW	10GWs	US$ 33-74/MWh	• Enhanced Geothermal Systems (EGS) using hot dry rocks • Improving resource exploration technology • Smaller plug-and-play modules for low-grade resource power conversion	• Drilling rig availability • Power plant construction delays • Permitting delays	• Rate support in the form of Renewable Portfolio Standard, Feed-in Tariff or Green Certificates • Country goals specific for geothermal • Accelerated planning process
8. Carbon Capture and Storage	18 $MtCO_2e$ injected in 2008, equivalent to CO_2 capture from 1.4GW generation	Very substantial	Currently over US$ 100 per tonne of CO2, but with potential to halve costs	• Reducing parasitic cost of capture to nearer thermodynamic limit • Understanding of long-term stability of CO_2 in subsurface geological environments • Developing technologies to monitor and remediate possible leakage	• Identification and permitting of points of injection and plants suitable for capture • Pipeline construction	• Clarity on emissions targets • Clarification of environmental legislation • Inclusion of captured CO2 in carbon trading systems • Capital support towards cost of pilot projects

Note: RPS – Renewable Portfolio Standard; PTC – Production Tax Credit

Source: New Energy Finance

Further details of each of these leading sectors is included in Appendix I, and summarized in Table 3. The relative scale, technology gaps, potential bottlenecks and policy requirements for each sector are outlined.
It is important to emphasize that these are by no means the only clean energy sectors of promise. There are many other emerging technologies – a wide range of biomass-based power generation approaches, wave and tidal power, ground source heat pumps, ocean thermal and osmotic power – each of which has substantial potential and its fervent admirers.

Nuclear power is also set for a renaissance in many countries around the world. Nuclear energy's share of total electricity production has remained steady at around 16% since the 1980s, when 218 reactors were built around the world. However, nuclear power will clearly be part of any future energy system, although its contribution will be limited by issues of cost, storage, safety and public resistance. We do not consider it in detail in this paper.

Although the eight key technologies highlighted here are not yet fully cost competitive on a levelized basis, i.e. without subsidies (see Figure 16), the economics of experience curves and fossil fuel depletion are working powerfully to level the playing field. Renewable energy is becoming cheaper as technologies increase in scale and operating experience. This trend has been obscured recently by surging commodity prices and supply chain bottlenecks, but with new industrial capacity coming on-line we are about to see falls in the cost of clean energy.

It should be noted that any comparison of levelized costs of different energy sources is a minefield:

- What cost should one use for each energy source? There is no single point number which can be used: costs vary by the nature of the resource, the distance to the source of demand, the age and efficiency of the local infrastructure.
- What is the levelized cost of competing technologies? Fossil-based energy has undoubtedly benefited from substantial public investment globally in the past, but in pure economic terms that should be treated as a sunk cost; any subsidies to the fossil fuel sector, however, must be taken into account. But what about the enormous contribution to national treasuries generated through fossil fuel taxes?
- What assumptions should be made about future prices of fossil fuels? And interest rates? Renewable energy, with most of its costs up-front, may win in a high-fuel-cost, low-interest-rate scenario, but not otherwise (see Table 2.). It is worth pondering in this context the impact of the current extreme monetary stimulus, coupled with the drop in oil and gas investment we are seeing around the world.
- How should one measure and attribute the "externality costs" of fossil-based energy? Burning fossil fuels has negative impact on public health and the environment – principally in terms of climate change – which are not borne by the energy sector. Over time, these externalities look set to be increasingly priced in to investment decisions, as shown by the abandonment of plans for scores of new coal-fired power stations in the US (e.g. the TXU transaction). We will look at the question of the role of carbon markets in spurring a shift to clean energy in Section 8.

As discussed above, the exact levelized cost of energy is contingent on an array of macroeconomic variables that can be difficult to forecast. Inputs such as prevailing interest rates, fuel prices and the market price of carbon can have large impacts on the final cost calculus. Table 2 shows a few examples of sensitivity analysis for these key variables. Electricity generation from renewable energy very often has little to no variable cost, instead front-loading the vast bulk of the lifetime cost in the upfront capital expenditures (capex). As opposed to natural gas generation, where the bulk of the lifetime cost is embedded in the variable fuel costs, capex-heavy generation is very dependent on the price of financing. In our low interest scenario, with a 300 basis point net drop in interest rates, solar PV and onshore wind fall by 8.1% and 10.4% respectively, while natural gas falls by only 1.3%. Capital costs for coal-fired plants have risen substantially over the last few years, making it also quite responsive to interest rate fluctuations. The fuel price and carbon price analysis show that natural gas has a significant advantage in a high carbon environment due to its relatively low emissions while coal cost rises precipitously by 45%.

The low interest, high carbon, and high fuel price scenario shows the plausibility of onshore wind, geothermal and biomass becoming competitive with fossil fuels unsubsidized and without significant cost reductions. In fact in many markets renewable energy is already becoming economically viable. While our global baseline average for natural gas sits at US$ 82/MWh, the high volatility of gas prices has lead many market operators to calculate a risk-adjusted cost of US$ 100-110/MWh, bringing onshore wind into the fray. In particularly sunny climates, solar PV and solar thermal correlate very well with demand peaks and already find themselves close to parity with peak power prices. While our best case scenario still leaves many forms of renewable energy generation with a sizeable gap to competing with fossil fuels, their rapid descent down the experience may push them into the energy mix faster than most expected.

7. Four Key Enablers

The shift to a low-carbon energy system will not be achieved simply through the addition of new sources of clean energy. It will also be necessary to make wholesale changes in the way energy is distributed, stored and consumed.

The cheapest and easiest way to reduce CO_2 emissions – particularly in the short term – will be through improving energy efficiency. Renewable energy, while plentiful and increasingly cheap, generally has the twin disadvantages of being intermittent, and not co-located with the source of demand. Investment will be required in power storage and in energy distribution systems, principally the grid. Finally, given the abundance and security of coal supplies, it is essential that we unlock the potential of carbon capture and sequestration (CCS) technology.

7.1 Energy Efficiency
Energy efficiency can make a significant contribution towards closing the gap between energy demand and supply. It has frequently been said that the cheapest source of energy is the energy never used. There are enormous opportunities for improving the efficiency of the world's energy infrastructure, both on the supply and on the demand side – and many of them could even produce returns above the cost of capital of any major business.

A McKinsey Global Institute report published in July 2008 – How the World Should Invest in Energy Efficiency – argues that targeting cost-effective opportunities in energy productivity could halve the growth in energy demand and cut emissions of greenhouse gases, while generating attractive returns for investors. Boosting energy efficiency will help stretch energy resources and slow down the increase in carbon emissions. It will also create opportunities for businesses and consumers to invest US$ 170 billion a year from now until 2020, at an attractive 17% average internal rate of return.

However, there are several barriers blocking investment in and adoption of energy efficiency technologies. Market and policy barriers include a general lack of consumer education, fuel subsidies that encourage (or at best fail to discourage) inefficient energy use, and an asymmetry of benefit that leaves landlords and tenants resistant to energy efficiency because they believe that the other side stands to gain more.

A further challenge is the fact the most energy efficient opportunities are in developing countries – McKinsey's analysis suggests that two-thirds of the US$ 170 billion required investment would go to developing economies, where it would be more efficiently used as the cost of abating a unit of energy is around 35% lower than in developed countries (because here, energy savings are more marginal and therefore expensive). But in developing countries, investment is harder to come by and there is a sense of "It's our turn now", which can make them particularly resistant to pressure from countries that have already enjoyed their industrial revolutions.

In terms of sector, most energy efficiency opportunities lie in the industrial sector (49%), followed by residential (23%), transport (15%) and commercial (13%). Many of these efficiencies could be realized quite easily and cost-effectively. For example, much of the potential for industrial energy efficiency is in emerging markets, such as China, where the cost of realizing them is on average 33% lower than in the US, and as much as 50% less in some other countries. Buildings can be even made energy positive, meaning they produce more energy than they consume by using integrate solar PV (roof, facade, window), chromic glass, heat-exchangers/pumps, smart devices, and smarter architectural building designs. In the residential sector, nearly 80% of the investment would be directed at just one area – installing more efficient heating and cooling systems in existing and new homes.

However, it should also be noted that the experience from countries such as Denmark and Japan has shown that exploiting energy efficiency opportunities requires sustained public policy support over an extended period. One particular barrier to achieving step change improvements in energy efficiency world is the nature of utility regulation in the developed world: as long as utilities are able to earn more – even after any penalties or fines – for selling more gas or electricity – they will have little real incentive to help their clients reduce energy demand. So you have the paradoxical situation whereby utilities, with the lowest cost of capital of any companies, raise money to build power stations to meet additional demand from clients who can easily make energy savings with extremely short payback periods. This is a problem that can, and must, be solved by a combination of changes to utility regulatory frameworks, combined with a revitalization of the Energy Service Company (ESCO) model, whereby third parties (including utilities) underwrite the capital cost of energy-saving improvements, and share in the resulting cash savings.

7.2 Smart Grid
As well as using what energy we generate more efficiently, we need to streamline power generated from a far more diverse range of sources than currently – and this will require substantial investment in electricity

networks around the world. The world's electricity grids were designed to distribute power cheaply and reliably from large centralized power stations to broadly distributed demand. The grid of the future will have to cope with decentralized, fluctuating supply. They will also be expected to deliver a far more sophisticated range of services to help with demand-side energy management. Only a new and fully digitally-enabled grid architecture will be able to meet these needs, and the investment requirement is estimated by New Energy Finance at US$ 10 trillion, (including US$ 6.8 trillion to repair and replace the existing transmission and distribution network). "Smart grid" technology will allow intermittent power from renewable sources such as wind and solar, as well as distributed generation, to be integrated into the grid alongside baseload power from conventional sources and nuclear energy. Sophisticated software to manage (and ideally match) electricity supply and demand in the most efficient way possible will ensure that power is delivered where and when it is needed.

Further downstream, there are a variety of technologies that aim to optimize energy supply and demand networks. Metering technologies can be used to monitor energy use in homes and offices, or individual energy-using devices. Metering data can incentivize owners to cut down on energy use, while a utility can use the information to help optimize their energy use. Smart grid technology developers create a real-time feedback loop between customers and suppliers allowing them to optimize their energy consumption during peak power events.

7.3 Power Storage

Power storage will be another key feature of the energy supply of the future. Across the energy system the need for energy storage is increasing, whether to power hybrid and electric vehicles, to smooth out fluctuations in supply and demand, balance intermittent renewables, or to extend appliance functionality. All application areas will provide investment opportunities in the coming years as the need for low cost, lightweight, high energy density technologies intensifies.

The hybrid vehicles of today use nickel metal hydride (NiMH) batteries. Next generation vehicles such as plug-in hybrids (PHEVs) or full electric vehicles (EVs) will most likely use lithium ion batteries. A number of start-up companies in the US and Europe are working on developing new low cost solutions. However, the battery alone will not determine the success of an EV and therefore design of the vehicle itself is of the utmost importance. As with batteries many new venture backed companies are developing new vehicles. Of course, the large automakers are working hard to develop technology of their own, however it is an area that most of left undeveloped for some time.

Technologies for bulk storage vary between traditional methods, such as pumped hydro and compressed air energy storage (CAES), to novel methods such as advanced batteries. For high power density applications, such as balancing short-term grid fluctuations, flywheels and ultracapacitors are beginning to be explored. Both pumped hydro and CAES require specific geographical and geological formations such as rivers that can be dammed or salt caverns, respectively. Therefore, batteries may be a more versatile next generation technology. In particular, sodium sulphur batteries or flow batteries such as vanadium redox have begun to be implemented for peak power load levelling and storage of intermittent wind energy. The cost of grid scale bulk storage for 1MWh of electricity ranges from US$ 40 to US$ 180, depending on the technology used.

Intermittent renewable energies such as wind will benefit greatly from power storage. Such functionality would provide enhanced reliability, balance frequency fluctuations from turbines and potentially allow for price arbitraging – selling wind generated off-peak during peak, high demand and high price electricity periods. However, battery technologies are still too expensive for price arbitraging. Prices will need to fall to US$ 50/MWh to prove economically feasible. New Energy Finance estimates that the current cost of utilizing battery technologies ranges from US$ 180/MWh for sodium sulphur batteries to US$ 114MWh for vanadium redox batteries. Several venture backed companies claim to be developing technologies that would provide significantly lower US$/MWh costs.

7.4 Carbon Capture and Storage

A major component to all models outlining potential solutions to climate change, carbon capture and storage (CCS) involves removing CO_2 from processes that utilize fossil fuels for power or industrial applications, then trapping it in subsurface geologic formations or using the gas for other purposes. As CCS is the predominant means by which the concept of clean coal is to come to fruition, and since coal-fired power generation accounts for 41% of global emissions, the potential for CCS deployment is enormous. However, up to now, CCS has experienced difficulties in gaining widespread use due to technical issues, but mostly because of insufficient legislative incentives, incomplete regulatory frameworks, and lack of public acceptance.

At present, government incentives are vastly insufficient to meet the high cost of capture and storage, which currently totals approximately US$ 115 per tonne CO_2 saved (and US$ 100 per tonne CO_2 saved for capture-only). By 2020 however, the market will be able to support extensive CCS deployment in the EU, Australia, US and Canada, although CCS, induced by trading programmes alone, will not exceed 275 million tonnes CO_2e injected per year. This number is a vast increase from the current yearly injection rate of 18 million tones CO_2e, but still only accounts for a reduction of roughly 1% of global emissions and is equivalent to the emissions from just 41 coal-fired power stations. Clearly, government mandates are needed to increase CCS as a means of carbon mitigation. Post 2020, the continuous lowering of emission targets will make CCS the essential abatement option for many countries and together with carbon trading will therefore ensure its further deployment.

The current push in CCS research and development is two fold; implementation of demonstration projects and improving CO_2 capture techniques. For CCS to become a widespread commercial option, the entire process from capture to storage and monitoring must be demonstrated on a utility scale. This has not yet happened, but several such projects are in planning, totalling over US$ 53 billion, and many smaller ones are currently underway. A major obstacle to the construction of large-scale demonstrations is cost, which is expected to decrease by more than half the current price, to US$ 30-60 per tonne CO_2 saved, as capture technology improves. There are currently over 190 capture technology demonstration projects underway worldwide.

Besides working out the technical and economic details of CCS, demonstration projects will serve to provide information necessary to establish effective regulatory frameworks. Several countries have completed drafts of such frameworks.

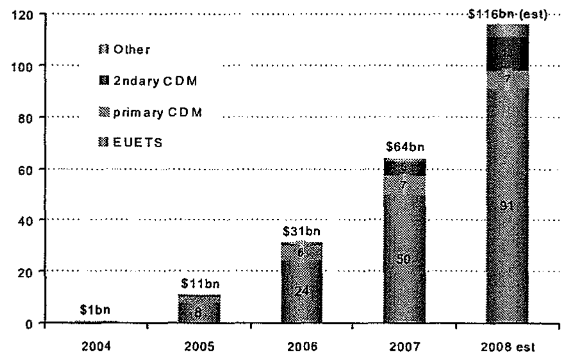
As carbon prices are unlikely to exceed US$ 50 per tonne in the short term, CCS demonstration projects, utility scale and smaller, will be completed only with strong assistance from the public sector, and will be coupled with revenue-generating activities such as enhanced oil recovery. However, post 2020, as carbon prices rise and the cost of capture decreases, CCS will become more and more a part of global emissions reductions.

8. Carbon Markets

We are moving inexorably towards a world in which greenhouse gas emissions will have a cost. Over the next two decades this will transform the economics not only of the energy sector, but of all energy-intensive industries. However, carbon pricing alone will not be sufficient to spur a shift to clean energy in the short to medium term. But over the longer term carbon prices will be an increasingly important driver of investment in clean energy.

Despite the turmoil in the world's financial markets, 2008 was another year of record growth in the carbon markets. Transaction value in the global carbon market grew 81% over the first nine months of 2008, reaching a total value of US$ 87 billion and is likely to exceed US$ 100 billion by the end of the year (see Figure 17).

Figure 17. Global Carbon Credit Trading Volume, 2004-2008, US$ billions



Source: UNFCCC data, New Carbon Finance analysis

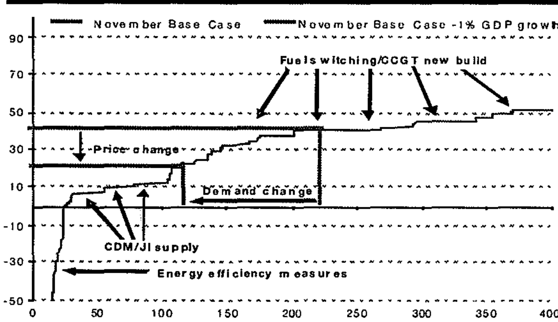
How Carbon Markets Work

Carbon markets do not trade carbon in the way that copper markets trade copper, or oil markets trade oil. What changes hands is the right to emit a certain volume of CO_2 or an equivalent amount of another greenhouse gas.

The intention is first to put a price on emissions that have until now been cost-free, and second to allow trade in permits, so that those who can most easily reduce emissions have the greatest incentive to do so. There are other ways of spurring emission reductions: governments can simply mandate them, perhaps demanding the use of energy-efficient technologies – but this brings all the risks of centralized control and picking technology winners. A carbon tax is the other solution often mooted. While simple to collect, it fixes the price of emissions but not their volume, which one can then only hope will be reduced according to plan.

Cap-and-trade, in principle (i.e. before allowing the trading of project-based credits from outside the capped region or industries), fixes the volume of emissions and then lets the market find the appropriate price level. In the short term, this may be driven by the usual factors – sentiment, liquidity, news-flow, momentum and so on – but in the long term, prices are driven by the number of credits created, the expected demand from industry, and the ease of closing any shortfall between supply and demand, using technology and investment available during the relevant commitment period (see Figure 18).

Figure 18. Drivers of Carbon Price – Supply, Demand and Abatement



Note: Supply of credits is decided by regulations governing each particular cap and trade scheme and commitment period. Demand for credits comes from the relevant regulated industries. Any shortfall can be met by a range of abatement approaches or project-based credits from the developing world. These are exploited in ascending order of cost according to the abatement curve for that scheme and time period. The clearing price is decided by the marginal abatement technology required to meet any shortfall.

Source: New Carbon Finance

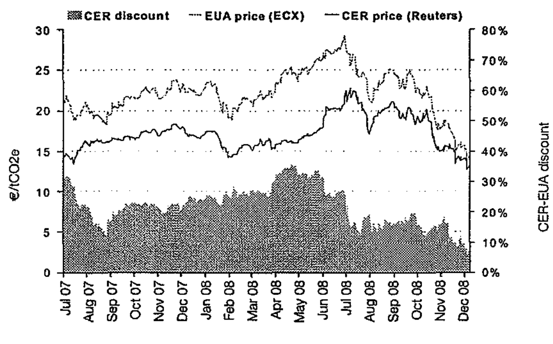
EU-ETS and Global Kyoto Compliance Markets

Currently the most liquid markets are the European Union Greenhouse Gas Emission Trading Scheme (EU-ETS) and the global Kyoto compliance market.

The EU-ETS, which started its second phase in 2008, covers some 45% of Europe's total greenhouse gas emissions. It has dominated carbon credit trading to date, accounting for 79% of transactions by value. Despite some downward movement in price towards the end of 2008 as a result of the global economic downturn, the average settlement price of European Union Emissions Allowances (EUAs) closed the year at around US$ 25 per tonne (see Figure 19).

The Kyoto compliance market arose because signatory governments in the developed world can purchase credits from emissions-reducing projects to contribute towards their reduction commitments. These can either

Figure 19. EU-ETS Price History: Phase II EUA and CER prices, July 2007-December 2008, €/tonne CO_2e



Source: ECX, New Carbon Finance (volumes are from ECX and BlueNext only)

be generated in the developing world under the Clean Development Mechanism (CDM), or in developed countries under the Joint Implementation Mechanism (JI). CDM credits, known as Certified Emission Reductions (CERs), accounted for 17% by value of carbon trading transactions under the EU ETS in 2008.

In order to qualify, each CDM project has to be registered with the UN. The process was initially hampered by bureaucratic delays, but there are now some 4,000 projects in the registration pipeline, which New Carbon Finance expects to yield some 1.5 billion CERs by 2012. This figure rises to more than 1.8 billion tonnes when an estimate for projects that have yet to enter the pipeline is included. Early CDM projects earned returns of hundreds of millions of dollars for modest investment by targeting industrial gases with greenhouse gas effects thousands of times more powerful than CO_2. Since then, however, the CDM has catalysed the investment of many billions of dollars in clean energy in developing countries.

By the end of 2008, 59% of all CDM projects were based on renewable energy or energy efficiency, although their modest size means they account for only 37% of CERs; this is expected to grow to nearly 60% by 2012 as the potential for industrial gas projects has largely been exhausted. By the end of 2012 we estimate that the CDM will have stimulated the flow of roughly US$ 15 billion from developed to developing projects for investment in low carbon projects in developing countries.

Other Emerging Carbon Markets

Where the EU ETS and the Kyoto Compliance Markets have led, others are now following. The Australian Carbon Pollution Reduction Scheme is scheduled to start operation in 2010. Japan is trialling a voluntary ETS after years of negotiation between government and powerful utilities and industry groups.

The US, which could – some would say should – be the deepest carbon credit market in the world, has been somewhat left behind, but is now making rapid progress. The Regional Greenhouse Gas Initiative is up and running, albeit with modest carbon reduction ambitions. California and the Western Climate Alliance are working on state-level or regional plans. Then there is the voluntary market, rapidly taking shape and increasing in volume. And President-Elect Obama has clearly stated his support for a federal cap-and-trade scheme.
The emerging mosaic of carbon markets may look chaotic, but what we are seeing is the emergence of a system of interlinked, policy-led financial markets, similar to today's currency markets.

Figure 20. Existing Multinational Initiatives Promoting Investment in Clean Energy

Several organizations and projects have been set up to share information and encourage investment in renewable energy, energy efficiency and the carbon markets. These include:

- Basel Agency for Sustainable Energy www.energy-base.org
- Carbon Disclosure Project www.cdproject.net
- CERES www.ceres.org
- Clean Energy Investment Working Group www.cleaninvestment.org/
- Energy Efficiency 21 www.ee-21.net
- European Energy Venture Forum www.europeanenergyventurefair.com
- Institutional Investors Group on Climate Change www.iigcc.org
- Investor Network on Climate Risk www.incr.com
- London Accord www.london-accord.co.uk
- Renewable Energy and Energy Efficiency Partnership www.reeep.org
- Sustainable Energy Finance Alliance www.sefalliance.org
- UNEP Sustainable Energy Finance Initiative www.sefi.unep.org

Source: New Energy Finance

Potential Future Developments

Perhaps the biggest problem the carbon market presents to investors – other than its sheer complexity – is its apparently uncertain future. The Kyoto Protocol in its current form lasts only until 2012. Two processes are under way, working to develop a successor regime: one involving those nations that have ratified Kyoto, and a second, the so-called Bali roadmap, which includes the US.

The December 2008 Poznan negotiating session, which took place after the US election but before the Inauguration of President Obama, produced little of substance, although this was not surprising. Issues debated included the adoption of emissions targets for large developing countries (India and China) – although this was firmly rejected, the structure of the CDM, the inclusion of credits from avoided deforestation and carbon capture and sequestration and, of course, the potential commitment by the US. President Obama has signified that such a commitment will be forthcoming under his leadership, and the world is holding its breath to see what comes out of negotiations in Copenhagen in December 2009. This is seen as the last chance if there is to be a solution in place before the current Kyoto arrangements expire in 2012, although missing that deadline does not mean the process is dead, so an extension is possible, if not probable.

Whatever happens in Copenhagen, the future of the EU ETS and CDM is secure. The EU has shown a strong commitment to climate goals in general – most recently passing the climate package which sets out its target of reducing emissions by 20% by 2020, and by 30% if other nations join in – and to the EU ETS in particular. It will also continue allow CDM credits to be used in lieu of local carbon reductions. New Carbon Finance's central forecast for the price of credits in Phase II of the EU ETS is for an increase from the current US$ 21 per tonne to US$ 40 per tonne in 2012. Beyond 2012 prices will continue to rise as carbon caps bite more deeply in the run-up to 2020 and beyond, and easy sources of credits are exhausted.

Summary: Carbon Markets – Necessary but not Sufficient

In summary, the long-term outlook for carbon remains bullish as momentum towards a network of national and regional schemes remains strong. However, it will be some time – possibly decades – before carbon credits alone provide an economic rationale for the large-scale roll-out of renewable energy, for the deployment of the key enabling technologies for such large-scale roll-out, or for commercial carbon capture and sequestration projects. If these goals are to be achieved, a broader range of policy tools is required.

9. Longer-Term Policy Requirements

Any shift to a low-carbon energy infrastructure will need to be supported by a range of policy tools: there will be no one-size-fits-all solution. A carbon price, while helpful, will not be sufficient to spur the deployment of renewable energy or carbon capture and sequestration for the foreseeable future. And even if policy-makers make incentives for clean energy a key element of their response to the current financial crisis, there will still be a need for further action. The industry needs a rational set of support mechanisms, tailored to each geography and sector.

While a carbon price is the logical foundation of any policy regime for clean energy, as we have seen, it cannot on its own spur the development of a healthy clean energy industry. It might drive a switch by utilities from coal to natural gas, boost energy efficiency and discourage deforestation, but it cannot stimulate the uptake of a variety of clean energy technologies at different stages of maturity. Nor can it catalyse the deployment of the key enabling technologies that will be required, including the digital grid and carbon capture and sequestration.

These goals will only be achieved by support tailored to the stage of commercialization of the sector in question:

- **Almost Commercial.** Sectors nearing maturity and competitiveness with fossil fuels need rate support only for a limited period to help them close the gap. Once a clean energy technology is within 20% of the cost of fossil energy, it should be able to stand on its own two feet, with utilities choosing to deploy it as a way of hedging against feedstock volatility (as demonstrated by the late Dr Shimon Awerbuch). But until this tipping point is reached, the goal should be to support renewable technologies during a finite period while suppliers drive their costs down.
- **Ready to Scale.** Technologies that work in the lab but are too risky to scale up need support and finance to bridge the "Valley of Death", which they must pass through in order to reach commercialization. Until the first full-scale plants are built, it is impossible to eliminate technology risk – which debt providers will not take. Yet equity providers will not make adequate returns without an element of debt funding. Specialist funds could help break this inherent circularity. Technologies currently falling into this "Valley of Death" might include marine power, next generation biofuels, large networks of plug-in hybrids and advanced geothermal, even very large-scale offshore wind turbines and solar thermal chimneys. Major public funds could be created to smooth the transition of these technologies across the Valley of Death. These should be sufficiently large to pool the risk of multiple technologies and projects; they should leverage the skill of private equity providers and insurance companies; and they should take only the final tranche of unavoidable technology risk.
- **Blue Sky.** Sectors with longer-term technological promise need research funds. Venture capital investment in clean energy technologies has exploded since 2005, but it is remarkable how small the total investment is – US$ 4 billion worldwide out of total clean energy industry investment of US$ 142 billion in 2008 (just 3%) – reflecting a shortage of "outside the box" ideas. There needs to be far higher investment in universities, national labs and other publicly-funded research into the fundamentals of energy technology. With the path to market for energy technology often taking 10 to 15 years, commercial players tend to under-invest in blue sky research – a gap that could be plugged by public funds.

But simply supporting chosen sectors will not be enough to develop and deploy new renewable energy technologies. An entire ecosystem of supporting technology and service providers will be fundamental to the growth of a healthy clean energy sector – and this is inextricably linked to the ability of entrepreneurs and companies to create new businesses. One of the reasons that Europe consistently lags venture investment in clean energy in the US by a factor of five to seven is that the **conditions for venture investment** in Europe are less well-developed.

Governments should also lead by example, creating markets for clean energy through **public procurement.** With central, regional and local government accounting for 35-45% of economic activity in all of the world's largest economies, public sector purchasing can be a powerful force. Clean energy use should be mandated in public procurement, which would create guaranteed markets for leading innovators in transport, heat and electricity.

Finally, policy-makers should enforce **energy efficiency standards.** Utilities and energy-intensive industries will respond to carbon prices and other price signals, but many individuals and businesses will simply not do so. As a result, there will always be a role for regulation to mandate certain changes in behaviour, such as appliance efficiency and standby power limits, corporate average fuel economy (CAFE) standards and building codes. They must also address the asymmetry between energy providers, who want their customers to use as much energy as possible, and consumers, who on the whole would prefer to use less.

But whichever policies are adopted, the overarching requirement is for policy stability – the impact of policy uncertainty on cost of capital must be better understood – and simplicity, so that the industry is not burdened with unnecessary bureaucratic costs.

Appendix - Target Sector Summaries

1. Onshore Wind

The most mature of the renewable energy sectors, the onshore wind industry saw 21GW built in 2007, bringing installed capacity to over 100GW. In Germany, Spain and Denmark wind power now supplies 3%, 11% and 19% respectively of total electricity production during the course of the year, and in Denmark up to 43% of the country's electricity demand at times of peak wind supply. Electricity from onshore wind can be generated at prices of 9-13 c/kWh, making it only 32% more expensive than natural gas CCGT, even in the absence of a carbon price. The Global Wind Energy Council forecasts that the global wind market will grow by over 155% to reach 240GW of total installed capacity by 2012.

Onshore wind can compete with conventional generation without subsidy, where wind speeds are high enough. However, there is no doubt that subsidy support, in the form of feed-in tariffs and tax credits, has spurred onshore wind development in countries such as Germany and the US.

Policy Status and Gaps

The wind industry has benefited from broadly supportive legislation, particularly in Europe and India which until recently has been home to the world's largest installed wind generation capacities, but now increasingly in North America and China. However, the industry needs a stable policy environment and reinforcement/renewal of existing policies if it is to continue to thrive. Political incentives to increase investment in the electricity grid will also boost the wind sector (along with all clean energy generation technologies).

Technology Gaps

Onshore wind is a mature sector, so advances in onshore turbine technology tend to focus on refining existing designs and increasing turbine size. The industry has been built on three-bladed upwind turbines whose design was popularized and commercialized by Danish companies in the late 1990s. More recently, though, very high demand growth has meant that market incumbents have been unable to keep pace and the sector is now seeing a re-emergence of older technologies and new manufacturers to commercialize them. This includes simplified two bladed turbines, downwind two bladed turbines and major innovations in offshore wind systems (see next section).

Other areas where better technology would boost the onshore wind sector include:

- Operations and maintenance, where marked improvements in existing asset management techniques are being pioneered through scale and closer inventory and technical team management
- Innovative technologies, either to reduce the cost of generation and the sector's exposure to volatile commodities (steel/copper)
- Supporting infrastructure for wind farms both in resource forecasting (high technology required) and grid expansion (mainly capital rather than technology required)

Potential Bottlenecks

Raising finance will remain a bottleneck in the short term, as it will for all energy projects. This is not only to do with less capital being available to finance onshore wind, but also because margins have broadened. Financing projects at a cost that makes economic sense will also be a challenge.

In the longer term, blade and turbine supply may constrain onshore wind development. Planning permission remains an issue, particularly in the most heavily populated and mature European markets, such as the United Kingdom.

Table 4. Onshore Wind – Economic Overview

Potential Scale	Greater than 1,000GW, of which only 100GW has been exploited.
Market Readiness	LCOE = US$ 89- 126/MWh
Project Returns	10-20% depending on market and resources

Source: New Energy Finance

Table 5. Top five wind markets by capacity, 2007

Market	Capacity (GW)
Germany	22.7
United States	16.9
	15.1
India	8.3
China	5.9

Source: New Energy Finance, GWEC

2. Offshore Wind

When the best sites for onshore wind have been snapped up, the next place to look for large quantities of renewable energy is offshore. Offshore wind offers enormous potential, with stronger more predictable winds and almost unlimited space for turbines. Planning permission can be easier to obtain, farms can be built at scales impossible on land, and the availability of space is almost unlimited if deep waters are mastered. At present, the cost of electricity from offshore wind is high – more than 16 c/kWh, but these will come down rapidly as more project experience is gained.

Offshore wind is relatively unexploited compared to onshore wind, but is coming into its own as the onshore market becomes saturated, particularly in densely populated areas such as Europe. However, offshore wind faces some logistical and design challenges, including the high cost of grid connection from offshore sites, higher wear and tear, and more difficult operation and maintenance.

Offshore wind tariffs and support mechanisms are currently being put in place to spur significant growth in Northern Europe, particularly in the United Kingdom and Germany where more than 1GW per year is expected to be commissioned over the next five years (see Figure 21). Other markets such as Belgium (0.8GW granted concession), Netherlands (150-200MW under construction), Denmark and Sweden will also provide demand for turbines and installation vessels.

The United Kingdom government has placed a growing emphasis on offshore wind to meet its long term renewable targets and as a hedge against rising gas imports. However, impatience with government procedure has led some industry participants to forge ahead with their own support plans for prototype turbines. For example, the Crown Estate, which owns more than half the United Kingdom's foreshore, tidal riverbeds and seabed rights, has committed to buy Clipper Windpower's first offshore wind turbine.

In the US high profile and contentious debate over the Cape Wind Project near Cape Cod has marred debate and to some extent distracted from the quality resources off the coast of major load centres where high electricity prices are common such as Virginia, Rhode Island, and New York.

Policy Status and Gaps

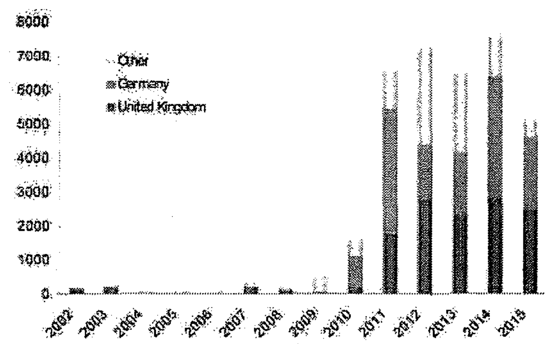
Offshore wind's long lead times, substantial capital spending (US$ 300m+) and long term operating risk mean that investors (primarily oil, gas and utilities) have made cautious but significant moves in the sector.
The United Kingdom and Germany are emerging as key markets, defined by steadily increasing policy support in the form of planning guidelines, feed-in tariffs and green "top-up" certificates. Elsewhere in Europe patchwork support is spurring some growth in Denmark, Sweden, Netherlands and Belgium, but higher than expected costs and capital spending uncertainty remains a challenge.

Table 6. Offshore Wind – Economic overview

Potential Scale	100GWs
Market Readiness	LCOE = US$ 158-205/MWhProject
Returns	Marginal

Source: New Energy Finance

Figure 21. Current and planned offshore wind projects by expected commissioning date (MW)



Source: Companies, Wind Associations (various), New Energy Finance

Technology Gaps

Offshore wind faces a substantially different and far harsher environment to onshore wind, with the result that early marinized versions of onshore turbines installed offshore suffered high profile and costly reliability issues. Significant work by Siemens, Vestas Repower and others have resolved many of the reliability issues by strengthening and improving components and insulating internal mechanisms from salt laden sea air.
This has come at a cost though with considerable compromises made on weight and upfront costs. Reducing the weight of the nacelle (at the top of the tower) either through removing or replacing electrical components, gearboxes or blades are still being actively pursued by numerous companies and it is likely that

innovations around turbines and foundations will improve the economics of offshore wind – as long as a stable demand environment is generated by governments.

Potential Bottlenecks

Offshore turbines have lower profit margins than onshore turbines; as long as onshore development continues to be healthy, turbine manufacturers will focus on producing onshore turbines, creating a potential bottleneck for offshore turbines.

3. Solar – Photovoltaic (PV)

PV technology has made very rapid strides in the past four years, in terms of reducing the cost of crystalline silicon (its main component) and commercializing thin film technology, with investment volume growing to US$ 50 billion in 2007-2008 (see Figure 22). Although there has been a bottleneck in the production of solar-grade silicon, new capacity is coming on line and costs are set to drop rapidly from US$ 4/W to US$ 2.60/W by the end of 2009, making unsubsidized solar PV generation costs comparable with daytime peak retail electricity prices of approximately 17 c/kWh in many sunny parts of the world.

PV has also flourished under generous incentive regimes in Germany and then Spain, encouraging high profile IPOs from silicon, wafer, cell and module manufacturers. These companies' values have soared because a severe shortage of silicon has driven up their products' price and ensured strong order books.

Other companies have capitalized on the silicon shortage by developing technologies that use less silicon in their solar modules, or that use other materials altogether. Although the global PV market has traditionally been dominated by crystalline silicon modules, New Energy Finance expects that thin-film modules (silicon and non-silicon based) will account for 18% of solar panels produced in 2008, up from 14% in 2007. Thin-film modules are cheaper to produce than conventional silicon modules, because they use less silicon and benefit from a more integrated manufacturing process.

Installed PV generation capacity worldwide is 13.3GW, a fraction of installed wind capacity. This is because solar is the most expensive renewable energy source in nearly all applications. While it is the best option in a few niches, such as grid-isolated telecommunications towers and calculators, these markets are tiny. The growth markets are for grid-connected power plants supported by generous incentives. PV will eventually become cost-competitive in some mainstream retail markets, and this will unlock substantial additional demand, but this is unlikely to happen for several years.

Policy Status and Gaps

Incentives are by far the most significant driver of the PV market, in the form of feed-in tariffs and/or tax credits. Where these have been provided, as in Japan, Germany, Spain, and California, PV has thrived. Conversely, where subsidies are being capped or phased out, as they were in Japan and more recently have been in Spain, installation falls away.

PV also requires mandatory net metering, as homeowners need easy two-way access to the grid to benefit from owning distributed generation.

Technology Gaps

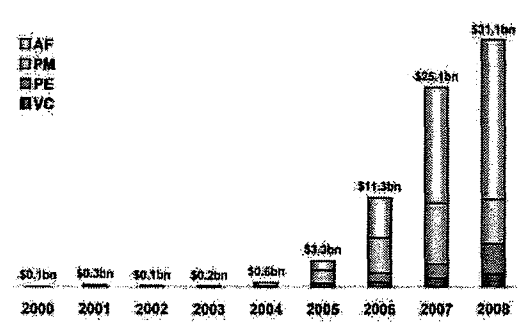
Mass manufacture of thin-film modules and reduction of cost for crystalline silicon modules are the key challenges for the solar industry. The next few years will be crucial, but if PV delivers on its near-term promises it will be cost-

Table 7. Solar PV – Economic Overview

Potential Scale	13.3GW currently installed Potential capacity limited only by economics
Market Readiness	LCOE = US$ 341-549/MWh Currently extremely uneconomical but with potential to halve in next 2 years
Project Returns	Heavily dependent on incentive regime

Source: New Energy Finance

Figure 22. Investment in solar (nearly all PV), 2000-2008: US$ million



Source: New Energy Finance

effective in many more niches and will need much less subsidy than at present.

Potential Bottlenecks

Over the next two years, oversupply of modules appears inevitable and the price is likely to fall to the marginal cost of production, representing a 40% fall for crystalline silicon modules. Shortage of affordable capital (the economics of PV are extremely sensitive to interest rates because nearly all the cost is upfront), caps to incentive regimes, customer inertia and permitting and transmission bottlenecks are therefore the main limits to the growth.

4. Solar Thermal Electricity Generation (STEG)

While PV is ideal for building-integrated and smaller projects, the technology of choice for big solar plants in the world's deserts looks set to be thermal: concentrating the heat of the sun to generate steam, which can be used in conventional and highly efficient turbines. There are relatively few projects up and running yet, but with costs of 24-30 c/kWh, this technology is shaping up to be a part of the solution in the sunniest parts of the world.

Solar Thermal Electricity Generation (STEG) – also known as Concentrated Solar Power (CSP) – comes in many different designs, the most mature being parabolic trough, but new ideas including tower and heliostat, Fresnel linear reflectors and parabolic dishes have been developed. All work on the same principle, of using mirrors to concentrate the sun's heat to produce steam that drives a turbine.

There is very little installed STEG capacity worldwide; just 438MW, although a further 131MW is due to be commissioned in Spain by the end of 2008. There is a large pipeline of STEG projects, mostly in Spain and the US but also several backed by government tenders in the Middle East and development bank funding in North Africa and Mexico (see Figure 23).

North Africa has excellent theoretical STEG potential – it has very high insolation, is eligible for funding from international development agencies and could be connected to Italy (and then to the rest of Europe) via a short submarine transmission cable. However, the region lacks the political support and grid connection to get the industry off the ground. In spite of this, some STEG plants are being developed, but most are add-ons to existing combined cycle gas turbine plants rather than stand-alone installations. In Morocco, for example, construction has started on the Ain-Beni-Mathar project, a 470MW combined cycle gas plant with a 20MW STEG component, funded by the National Electricity Office, the African Development Bank and the Global Environment Fund.

The first operational STEG plant was the Luz parabolic trough plant in the Mojave Desert, California. This was built in the late 1980s and early 1990s, and although the developer was forced into bankruptcy, it has been operating ever since.

Policy Status and Gaps

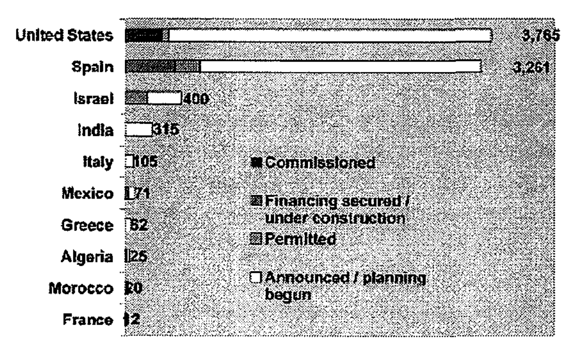
Like PV, STEG is highly subsidy-dependent, and there are only two near-term markets: Spain and the US. Spain's future after 2011 is uncertain, because once 425MW of STEG is installed, there will be a window of 12-24 months for further projects to be commissioned under the current regime. In the US, the eight-year Investment Tax Credit and utility willingness to contract for STEG to meet Renewable Portfolio Standards give the industry certainty. In other markets, progress on government tenders and development projects is slow.

Table 8. Solar Thermal - Economic Overview

Potential Scale	438MW currently Scale limited only by space and grid connection has been exploited.
Market Readiness	LCOE = US$ 241-299/MWh Uneconomic
Project Returns	n/a

Source: New Energy Finance

Figure 23. STEG pipeline by country and status, 2008, MW



Source: New Energy Finance

Technology Gaps

While parabolic trough is essentially a mature technology, and turbine design is unlikely to see any breakthroughs, new STEG collector designs have the potential to improve PV's economics when their technology is proven. Funding for the first large-scale plants, however, will be difficult as they will involve technology risks.

Potential Bottlenecks

In Spain, there are no bottlenecks for those with projects in the pipeline. In the US, permitting and transmission access will keep most planned projects on the drawing board for at least a year, and once those are overcome, it may not be easy to raise the necessary capital.

5. Sugar-based Ethanol

The period 2004-2006 saw US investment in biofuels soar, with investors pouring US$ 9.2 billion into the sector (see Figure 24). But most of this flowed into corn-based ethanol, which is more expensive to produce than sugar-based ethanol, subject to volatile prices and controversial because its feedstock is a food as well as a fuel. Many investors regretted their haste. By contrast, Brazilian sugar cane-based ethanol is competitive with oil at US$ 40 per barrel; it grows well in many southern hemisphere countries (and far from the Amazon); and there is no shortage of land to increase production substantially without jeopardizing food production in the region.

Sugar cane is the most cost-efficient and environmentally friendly feedstock for ethanol production with 70-90% fewer CO_2 emissions than gasoline, but it can only be grown under specific climate and soil conditions in southern hemisphere countries. Brazilian sugar cane ethanol is competitive with petrol at US$ 40 a barrel, but ethanol from other feedstocks, such as maize, is not economic without subsidy. The US ethanol market in particular has suffered as corn prices have soared since 2006, making production uneconomic in many cases and forcing producers to scale back their expansion plans. Corn ethanol also suffers from the food-fuel controversy, as well as relatively unimpressive emissions reductions (up to 30%).

Global ethanol production capacity is 70 billion litres per annum (Lpa). Brazil and the US are the two largest ethanol producers in the world, producing respectively 27 billion Lpa and 35 billion Lpa.

Policy Status and Gaps

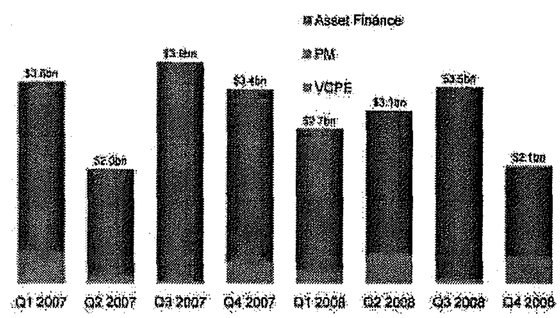
Most countries seeking to promote ethanol use do so by imposing a minimum blending requirement, although the well-established markets of Brazil and the US have discretionary blending. Ethanol can be used in ordinary vehicles in a blend of up to 25% without engine conversion, making widespread adoption a viable prospect.

Table 9. Sugar-based Ethanol – Economic Overview

Potential Scale	70 billion Lpa commissioned production capacity Global production estimated to reach 255 billion Lpa by 2030
Market Readiness	Brazilian sugar ethanol is market-ready i.e. competitive in its own right with oil at US$ 40/barrel
Project Returns	n/a

Source: New Energy Finance

Figure 24. Investment in Sugar/Maize Ethanol, US$ million



Source: New Energy Finance

Policy is a key driver of ethanol markets, both domestically and internationally. Ethanol benefits from blending mandates and local subsidies; but the operation of a global market is inhibited by widespread import tariffs that put Brazilian ethanol in particular at a disadvantage to locally produced ethanol in the US and other countries. France, however, recently announced that it would reduce and eventually cut its subsidies to domestic ethanol producers by 2012, and other countries may follow its lead.

Ending import tariffs and defining international standards would also boost the international ethanol market, avoiding market distortions and allowing for free trade and long term international trade contracts. Brazil, which understandably lobbies for the removal of import tariffs, has some support from the US, Sweden and international trade organizations.

Brazilian ethanol production would benefit from legislation to allow for the use of transgenic (genetically modified) cane, currently banned by the Brazilian Ministry of Science and Technology.

Technology Gaps

Sugar-based ethanol is produced from sugar cane juice, but technology is being developed so that all cane residues – leaves, straw and bagasse – can be used for ethanol production, through processes like hydrolysis, increasing sugar cane ethanol productivity significantly.

Genetically modified sugar cane cannot be commercialized in countries like Brazil, but transgenic cane technology has nevertheless been developed by companies like Alellyx in Brazil (recently acquired by Monsanto for US$ 287m), and could boost sugar cane's productivity by 20%.

Potential Bottlenecks

Falling oil price – and reduced crush spread – is the ethanol market's biggest challenge currently. With oil below US$ 40/barrel, even Brazilian ethanol ceases to be competitive overseas, although it remains in demand domestically.

Import tariffs and local subsidies also create a bottleneck for sugar-based ethanol. Once these are removed and a more level international playing field created, market mechanisms such as hedging instruments and a futures market will help build a transparent global ethanol market.

6. Cellulosic and Next Generation Biofuels

The argument over food vs fuel is an emotive one. In most regions, there is sufficient land to increase biofuel production from the current 1% of transport fuel to 3% or even 5% without impacting on food availability. But after that the only way to increase production of biofuels will be to source feedstock that does not compete with food. Luckily, the cost of producing biofuels from agricultural waste through cellulosic conversion and algae is coming down rapidly, and the future fuel system is likely to include a proportion of fuels from these sources.

As well as using byproducts of other crops, such as wheat straw, sugar cane leaves and forestry waste, crops are being grown specifically to produce biofuels, including jatropha (being trialled in India), miscanthus, and switchgrass. These crops have the added advantage of being able to grow in areas considered marginal for arable use, such as desert areas (jatropha) and very wet land (miscanthus). New technologies have been developed to cope with these more varied feedstocks, including enzymatic hydrolysis and gasification.

Global production of next generation biofuels is currently small – around 10 mLpa, compared to 69,900 mLpa of sugar-based ethanol – accounting for just 0.02% of global bioethanol production. However, this is expected to rise as new feedstocks are grown, technologies proven and scaled up, and the cost of production falls. Early-stage investment in second generation biofuels overtook first generation investment in the second and third quarters of 2008 (see Figure 25), although current economic conditions may reverse this trend in 2009.

Policy Status and Gaps

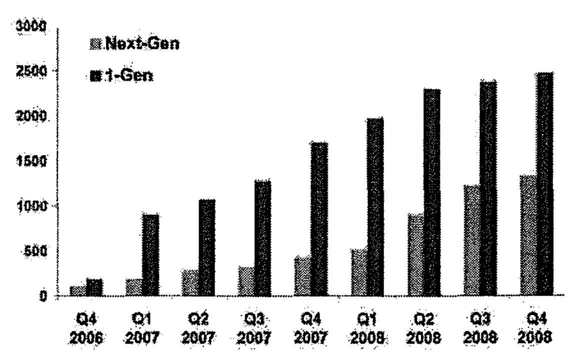
Policies supporting next generation biofuels are essentially the same as those relating to sugar-based ethanol (see above), including blending mandates, tax breaks, biofuel producers subsidies and feedstock

Table 10. Next Generation Biofuels – Economic Overview

Potential Scale	10 mLpa commissioned production capacity currently
Market Readiness	5-7 years away from commercial production
Project Returns	n/a

Source: New Energy Finance

Figure 25. Venture Capital and Private Equity Investment in Biofuels – First Generation vs Next Generation, US$ million



Source: New Energy Finance

cultivation subsidies. However, policy is starting to differentiate between first and next generation biofuels, in favour of the latter. In the US, for example, there is a mandate within the renewable fuel standard for a specific proportion of next generation biofuels.

In some countries, governments are giving farmers incentives to grow crops specifically for energy use, such as jatropha in India. Uptake has been poor, however, with farmers proving reluctant to run the risk of producing a crop whose yields are unproven, which may damage the soil and for which there is not yet an established market

The market needs capital support, in particular government funding for demonstration-scale projects to prove the technology is viable/scalable as well as encouraging farmers to invest in feedstock production. Financial incentives to encourage farmers to grow energy crops are also vital to overcome their initial caution.

Blending subsidies offering tax breaks to oil companies who blended next generation biofuels into their products, provided over a reasonably long time horizon (4-8 years) would also help reduce operating costs and give farmers, producers and developers an incentive to invest.

Technology Gaps
Research and development is still focusing on which crops can be grown successfully on marginal land, and also which can be grown economically.

The key challenge for next generation biofuels is to lower production costs sufficiently to compete with conventional energy, and also with first generation biofuels, particularly sugar cane ethanol. Next generation biofuel production processes that fit easily and inexpensively into existing production capacity have the best chance of success.

Potential Bottlenecks
As with sugar-based ethanol, a falling oil price is a threat to investment into the sector, even though blending mandates provide the industry with some support. Otherwise, logistics is potentially a bottleneck. Feedstock is typically bulky and therefore expensive to transport long distances. Making sure that feedstock is grown as near as practical to processors and produced to the right specification is crucial.

7. Geothermal
Geothermal power is particularly attractive as a renewable energy source because it can be used as predictable base-load power in a way that wind and solar power cannot be.

Geothermal taps the naturally-occurring heat stored in rock up to several miles below the surface of the earth. The extraction process is relatively simple in theory: a series of holes are drilled into the ground and the subterranean heat is captured by drawing to the surface the naturally occurring steam or hot fluid. The steam is then run through a turbine directly, or the hot geothermal fluid used to heat a separate working fluid that converts to a gas to turn the turbine. In both cases, the used geothermal fluid is injected back into the subsurface to aid in replenishing the resource.

Until now, geothermal power has been used only in limited regions, but a raft of new approaches has helped make it economically viable across a wider area. In addition, all countries can exploit geothermal resources for ground source heat pumps or district heating, if not for large-scale electricity generation. Notable production advances are taking place in the US, the Philippines, Indonesia, Iceland, New Zealand, Australia, Turkey, and Germany. Spurred in part by regulatory support, there is now a large geothermal development pipeline, especially in the US.

Global installed capacity at the end of 2007 was estimated to be 10GW (see Figure 26).

Policy Status and Gaps
Renewable Portfolio Standards (RPS) help investors overcome the high up-front capital investment and financial risks of geothermal. Because geothermal is baseload power, it receives favourable pricing from utilities required to include renewables in their energy mixes. The large development pipeline in the US illustrates the positive effect of policy.

While tax credits, feed-in tariffs and national geothermal targets further spur geothermal investment, RPS is the key policy driver.

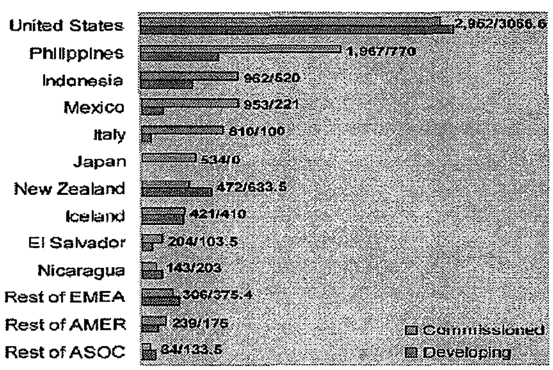
Technology Gaps
Enhanced Geothermal Systems (EGS) extract heat by creating a subsurface fracture system into which water is injected. EGS "enhance" or create geothermal systems where natural fractures provide inadequate flow rates. The appeal of EGS is that poorly producing resources can be improved and non-productive ones made productive: if the technology is successful, geothermal electricity could be produced anywhere in the world. The resource potentials for EGS are vast – estimated at 517GW for just the US. The first pilot EGS plant came online in France in June 2008, but research is being carried out elsewhere, including Australia, where the world's largest EGS (5-10GW) is being built.

Table 11. Geothermal – Economic Overview

Potential Scale	10GW currently installed 24.5GW potential capacity by 2030
Market Readiness	LCOE = US$ 33-74/MWh
Project Returns	n/a

Source: New Energy Finance

Figure 26. Global Commissioned and Developing Geothermal Capacity, Jan 2008: MW



Note: Labels denote installed/developing capacity in MW

Source: New Energy Finance

Improvements in exploration technology would facilitate development of resources with no surface manifestations. In the US, for example, these resources are estimated to be 33GW. Better exploration technology would also improve the current drilling success rate in greenfield sites of just 20%, dramatically cutting development costs.

Smaller "plug-and-play" units are being developed to use resources that were previously uneconomical because of low flow rates, projects of 10-15MW. UTC is one of the leaders in this area.

Potential Bottlenecks

As more companies become involved in developing geothermal projects, their fast growth risks eclipsing the available contractors and creating a construction bottleneck, increasing lead times and capital costs. Already there are long lead times (6-18 months) for drilling rigs – there is a shortage of specialist geothermal rigs (or ones that have been modified to cope with the more demanding geologies associated with geothermal). This is encouraging vertical integration (developers buying drilling companies) as well as developers and "drilling clubs" booking up rigs for long periods. There is also a backlog of plant orders as manufacturers struggle to keep pace with demand from the large project pipeline.

Long lead times for land siting, permitting and rights of way are other major bottlenecks for the geothermal sector. This could be eased by relaxing certain rules and streamlining the process.

8. Carbon Capture and Storage

No discussion of the future energy infrastructure would be complete without considering Carbon Capture and Storage. Although there are no installations at scale yet, almost 200 projects are at varying degrees of completion around the globe. With so many countries – including China and the US – dependent on coal-fired power, it is inevitable that CCS will form part of the solution to hitting CO_2 concentrations of 450ppm. In 2008, for the first time, the IEA's World Energy Outlook report included CSS as a technology that would be viable – and important – by 2020.

CCS is an early-stage technology. While it can be profitable in some cases, for example when combined with enhanced oil recovery (EOR) or where a levy on CO_2 emissions is in place (such as Norway), adding CSS to conventional power generation projects does not currently make economic sense (see Figure 27).
Using the technology available at the moment, CCS increases the plant's overall costs by as much as 85% and significantly reduces its overall efficiency because of the extra energy required to run the capture equipment. While it is accepted that CCS can reduce fossil fuel emissions, CCS's substantial cost has so far deterred large emitters from developing large-scale CCS projects. Instead investment has gone towards smaller scale projects that will serve as a springboard for development if a more stringent carbon reduction policy makes CCS economically viable.

18 million tones (Mt) CO_2e were injected in 2008, equivalent to the CO_2 emissions of 1,385MW of coal-fired generation (approximately 3 large coal-fired power plants)

Policy Status and Gaps

Key drivers for CCS include national and/or regional emissions standards (restricting how much CO_2 and other greenhouse gases power generators and industries can emit); subsidies that help bridge the gap between the cost of installing and running CCS, and the time when it becomes economically viable (or imperative) to run the technology; and carbon trading systems, which put a transparent value on CO_2 emissions and allow emitters to capitalize on reducing their CO_2 emissions

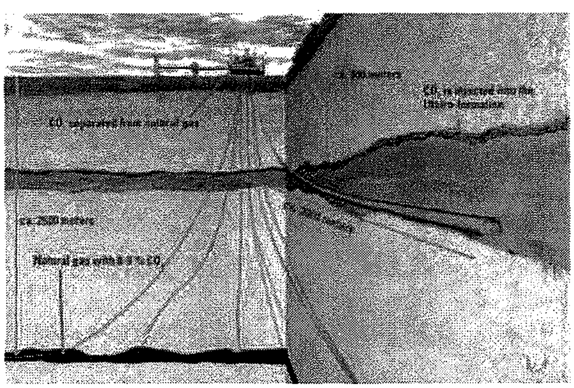
The United Kingdom government has taken a lead in encouraging the construction of the first utility-scale project by setting up a contest whose prize is up to 100% of CCS retrofit to capture at least 90% of emissions on 300 MW of an existing coal-fired power plant. Bids have been submitted and are under review.

Table 12. Carbon Capture and Storage – Economic Overview

Potential Scale	18 $MtCO_2e$ injected in 2008, equivalent to CO_2 capture from 1.4GW generation
Market Readiness	The viability of CCS is entirely dependent on the existence of the carbon markets and CO_2 price
Project Returns	n/a

Source: New Energy Finance

Figure 27. Global Commissioned and Developing Geothermal Capacity, Jan 2008: MW



Source: Statoil

Technology Gaps

The big challenge for CCS is establishing its technical and economic feasibility. Once a stable carbon price is in place and CCS is viable on a large scale – both in terms of CO_2 stored and the cost of doing so – the industry will take off. As the most expensive part of the CCS chain, carbon capture is a focus for research and development investment.

Within the overarching goal of cutting costs, technology is needed to understand the long-term behaviour of CO_2 in different subsurface geological environments. The goal of this research is to certify that CO_2 injected will be stored safely and securely over geologic time, and to ensure proper credit can be given to those that store, rather than emit, CO_2. CO_2 storage research is also designed to win public acceptance of CCS.

Potential Bottlenecks

Identifying sites suitable for CO_2 storage, where injection points can be made, and also, at the other end, plants suitable for capture. Although there are enormous potential global reserves for CO_2 storage, the number of sites suitable as actual injection sites is considerably less.

Building a CCS infrastructure is another potential bottleneck. If a CCS industry is to take shape, thousands of kilometres of CO_2 pipeline to go from source to sink, or connect to a CO_2 pipeline network, must be built. 90% of all installed CO_2 pipelines are in the US, although 81% of announced CCS projects are in other countries, highlighting the scope for investment in building CO_2 pipeline.

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Appendices
Global Wind Energy Council (GWEC) – wind industry statistics
Statoil – carbon capture and storage diagram

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Michael earned his Masters in Engineering from Cambridge, winning the Ricardo Prize for Thermodynamics, and has an MBA from Harvard Business School. From 1986 to 1993 he was a member of the British Ski Team, competing in the World Cup and the 1992 Albertville Olympic Games. He is Chairman of the St Marks Hospital Foundation, a medical charity.

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3

Climate change and its impacts in the near and long term under different scenarios

3.1 Emissions scenarios

There is *high agreement* and *much evidence*[9] that with current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. Baseline emissions scenarios published since the IPCC Special Report on Emissions Scenarios (SRES, 2000) are comparable in range to those presented in SRES (see Box on SRES scenarios and Figure 3.1).[10] *{WGIII 1.3, 3.2, SPM}*

The SRES scenarios project an increase of baseline global GHG emissions by a range of 9.7 to 36.7 $GtCO_2$-eq (25 to 90%) between 2000 and 2030. In these scenarios, fossil fuels are projected to maintain their dominant position in the global energy mix to 2030 and beyond. Hence CO_2 emissions from energy use between 2000 and 2030 are projected to grow 40 to 110% over that period. *{WGIII 1.3, SPM}*

Studies published since SRES (i.e. post-SRES scenarios) have used lower values for some drivers for emissions, notably population projections. However, for those studies incorporating these new population projections, changes in other drivers, such as economic growth, result in little change in overall emission levels. Economic growth projections for Africa, Latin America and the Middle East to 2030 in post-SRES baseline scenarios are lower than in SRES, but this has only minor effects on global economic growth and overall emissions. *{WGIII 3.2, TS.3, SPM}*

Aerosols have a net cooling effect and the representation of aerosol and aerosol precursor emissions, including sulphur dioxide, black carbon and organic carbon, has improved in the post-SRES scenarios. Generally, these emissions are projected to be lower than reported in SRES. *{WGIII 3.2, TS.3, SPM}*

Available studies indicate that the choice of exchange rate for Gross Domestic Product (GDP) (Market Exchange Rate, MER or Purchasing Power Parity, PPP) does not appreciably affect the projected emissions, when used consistently.[11] The differences, if any, are small compared to the uncertainties caused by assumptions on other parameters in the scenarios, e.g. technological change. *{WGIII 3.2, TS.3, SPM}*

Scenarios for GHG emissions from 2000 to 2100 in the absence of additional climate policies

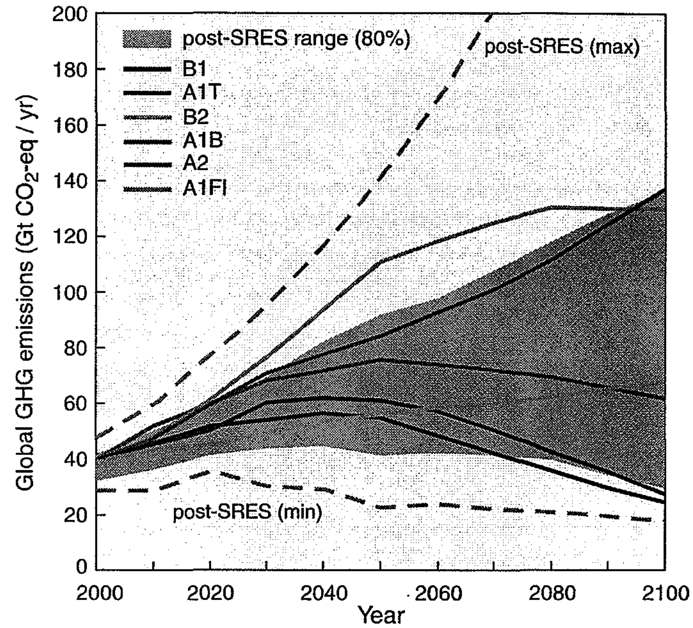

Figure 3.1. *Global GHG emissions (in $GtCO_2$-eq per year) in the absence of additional climate policies: six illustrative SRES marker scenarios (coloured lines) and 80th percentile range of recent scenarios published since SRES (post-SRES) (gray shaded area). Dashed lines show the full range of post-SRES scenarios. The emissions include CO_2, CH_4, N_2O and F-gases. {WGIII 1.3, 3.2, Figure SPM.4}*

SRES scenarios

SRES refers to the scenarios described in the IPCC Special Report on Emissions Scenarios (SRES, 2000). The SRES scenarios are grouped into four scenario families (A1, A2, B1 and B2) that explore alternative development pathways, covering a wide range of demographic, economic and technological driving forces and resulting GHG emissions. The SRES scenarios do not include additional climate policies above current ones. The emissions projections are widely used in the assessments of future climate change, and their underlying assumptions with respect to socio-economic, demographic and technological change serve as inputs to many recent climate change vulnerability and impact assessments. *{WGI 10.1; WGII 2.4; WGIII TS.1, SPM}*

The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 describes a convergent world, with the same global population as A1, but with more rapid changes in economic structures toward a service and information economy. B2 describes a world with intermediate population and economic growth, emphasising local solutions to economic, social, and environmental sustainability. A2 describes a very heterogeneous world with high population growth, slow economic development and slow technological change. No likelihood has been attached to any of the SRES scenarios. *{WGIII TS.1, SPM}*

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[9] Agreement/evidence statements in italics represent calibrated expressions of uncertainty and confidence. See Box 'Treatment of uncertainty' in the Introduction for an explanation of these terms.

[10] Baseline scenarios do not include additional climate policies above current ones; more recent studies differ with respect to UNFCCC and Kyoto Protocol inclusion. Emission pathways of mitigation scenarios are discussed in Topic 5.

[11] Since the TAR, there has been a debate on the use of different exchange rates in emissions scenarios. Two metrics are used to compare GDP between countries. Use of MER is preferable for analyses involving internationally traded products. Use of PPP is preferable for analyses involving comparisons of income between countries at very different stages of development. Most of the monetary units in this report are expressed in MER. This reflects the large majority of emissions mitigation literature that is calibrated in MER. When monetary units are expressed in PPP, this is denoted by GDP_{ppp}. {WGIII SPM}

3.2 Projections of future changes in climate

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. Even if the concentrations of all GHGs and aerosols had been kept constant at year 2000 levels, a further warming of about 0.1°C per decade would be expected. Afterwards, temperature projections increasingly depend on specific emissions scenarios (Figure 3.2). *{WGI 10.3, 10.7; WGIII 3.2}*

Since the IPCC's first report in 1990, assessed projections have suggested global averaged temperature increases between about 0.15 and 0.3°C per decade from 1990 to 2005. This can now be compared with observed values of about 0.2°C per decade, strengthening confidence in near-term projections. *{WGI 1.2, 3.2}*

3.2.1 21st century global changes

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. *{WGI 10.3}*

Advances in climate change modelling now enable best estimates and *likely* assessed uncertainty ranges to be given for projected warming for different emissions scenarios. Table 3.1 shows best estimates and *likely* ranges for global average surface air warming for the six SRES marker emissions scenarios (including climate-carbon cycle feedbacks). *{WGI 10.5}*

Although these projections are broadly consistent with the span quoted in the TAR (1.4 to 5.8°C), they are not directly comparable. Assessed upper ranges for temperature projections are larger than in the TAR mainly because the broader range of models now available suggests stronger climate-carbon cycle feedbacks. For the A2 scenario, for example, the climate-carbon cycle feedback increases the corresponding global average warming at 2100 by more than 1°C. Carbon feedbacks are discussed in Topic 2.3. *{WGI 7.3, 10.5, SPM}*

Because understanding of some important effects driving sea level rise is too limited, this report does not assess the likelihood, nor provide a best estimate or an upper bound for sea level rise. Model-based projections of global average sea level rise at the end of the 21st century (2090-2099) are shown in Table 3.1. For each scenario, the mid-point of the range in Table 3.1 is within 10% of the TAR model average for 2090-2099. The ranges are narrower than in the TAR mainly because of improved information about some uncertainties in the projected contributions.[12] The sea level projections do not include uncertainties in climate-carbon cycle feedbacks nor do they include the full effects of changes in ice sheet flow, because a basis in published literature is lacking. Therefore the upper values of the ranges given are not to be considered upper bounds for sea level rise. The projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flow rates could increase or decrease in the future. If this contribution were to grow linearly with global average temperature change, the upper ranges of sea level rise for SRES scenarios shown in Table 3.1 would increase by 0.1 to 0.2m.[13] *{WGI 10.6, SPM}*

Table 3.1. *Projected global average surface warming and sea level rise at the end of the 21st century. {WGI 10.5, 10.6, Table 10.7, Table SPM.3}*

Case	Temperature change (°C at 2090-2099 relative to 1980-1999) [a, d]		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	*Likely* range	Model-based range excluding future rapid dynamical changes in ice flow
Constant year 2000 concentrations[b]	0.6	0.3 – 0.9	Not available
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

Notes:

a) These estimates are assessed from a hierarchy of models that encompass a simple climate model, several Earth Models of Intermediate Complexity, and a large number of Atmosphere-Ocean General Circulation Models (AOGCMs) as well as observational constraints.

b) Year 2000 constant composition is derived from AOGCMs only.

c) All scenarios above are six SRES marker scenarios. Approximate CO_2-eq concentrations corresponding to the computed radiative forcing due to anthropogenic GHGs and aerosols in 2100 (see p. 823 of the WGI TAR) for the SRES B1, AIT, B2, A1B, A2 and A1FI illustrative marker scenarios are about 600, 700, 800, 850, 1250 and 1550ppm, respectively.

d) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C.

[12] TAR projections were made for 2100, whereas the projections for this report are for 2090-2099. The TAR would have had similar ranges to those in Table 3.1 if it had treated uncertainties in the same way.

[13] For discussion of the longer term see Sections 3.2.3 and 5.2.

3.2.2 21st century regional changes

There is now higher confidence than in the TAR in projected patterns of warming and other regional-scale features, including changes in wind patterns, precipitation and some aspects of extremes and sea ice. *{WGI 8.2, 8.3, 8.4, 8.5, 9.4, 9.5, 10.3, 11.1}*

Projected warming in the 21st century shows scenario-independent geographical patterns similar to those observed over the past several decades. Warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and northern North Atlantic, continuing recent observed trends (Figure 3.2 right panels). *{WGI 10.3, SPM}*

Snow cover area is projected to contract. Widespread increases in thaw depth are projected over most permafrost regions. Sea ice is projected to shrink in both the Arctic and Antarctic under all SRES scenarios. In some projections, Arctic late-summer sea ice disappears almost entirely by the latter part of the 21st century. *{WGI 10.3, 10.6, SPM; WGII 15.3.4}*

It is *very likely* that hot extremes, heat waves and heavy precipitation events will become more frequent. *{SYR Table 3.2; WGI 10.3, SPM}*

Based on a range of models, it is *likely* that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea-surface temperatures. There is less confidence in projections of a global decrease in numbers of tropical cyclones. The apparent increase in the proportion of very intense storms since 1970 in some regions is much larger than simulated by current models for that period. *{WGI 3.8, 9.5, 10.3, SPM}*

Extra-tropical storm tracks are projected to move poleward, with consequent changes in wind, precipitation and temperature patterns, continuing the broad pattern of observed trends over the last half-century. *{WGI 3.6, 10.3, SPM}*

Since the TAR there is an improving understanding of projected patterns of precipitation. Increases in the amount of precipitation are *very likely* in high-latitudes, while decreases are *likely* in most subtropical land regions (by as much as about 20% in the A1B scenario in 2100, Figure 3.3), continuing observed patterns in recent trends. *{WGI 3.3, 8.3, 9.5, 10.3, 11.2-11.9, SPM}*

3.2.3 Changes beyond the 21st century

Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised. *{WGI 10.4, 10.5, 10.7, SPM}*

If radiative forcing were to be stabilised, keeping all the radiative forcing agents constant at B1 or A1B levels in 2100, model experiments show that a further increase in global average temperature of about 0.5°C would still be expected by 2200. In addition, thermal expansion alone would lead to 0.3 to 0.8m of sea level rise by 2300 (relative to 1980-1999). Thermal expansion would continue for many centuries, due to the time required to transport heat into the deep ocean. *{WGI 10.7, SPM}*

Atmosphere-Ocean General Circulation Model projections of surface warming

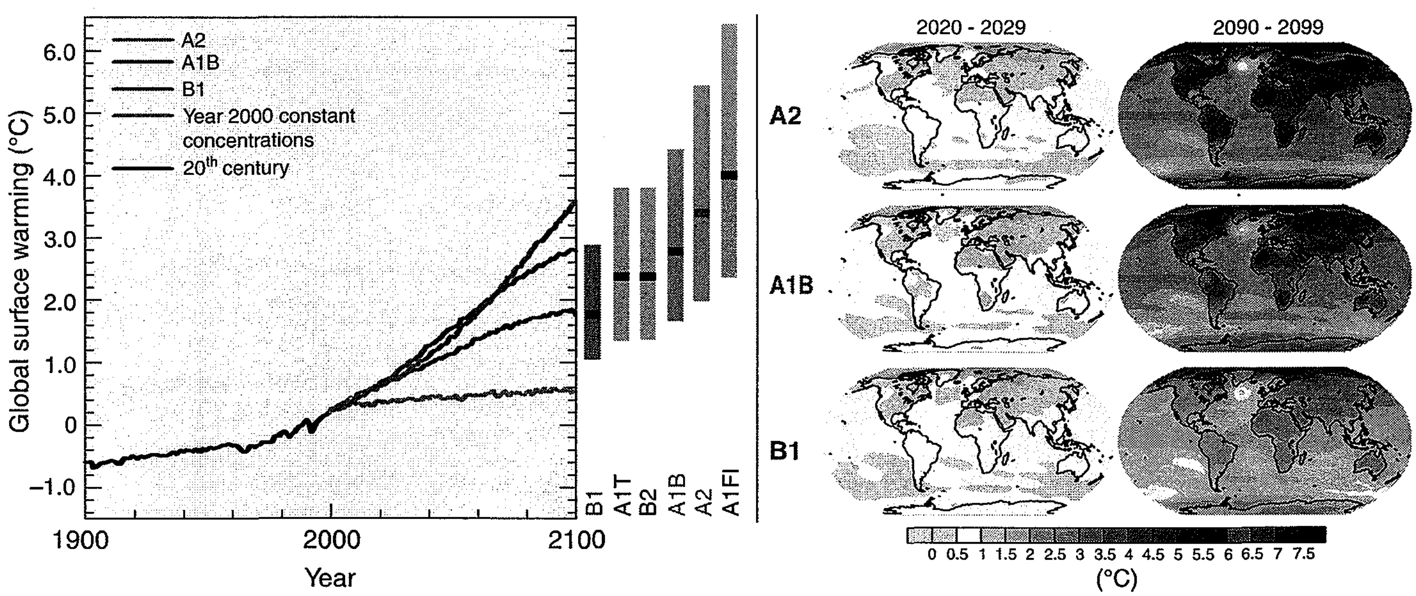

__Figure 3.2. Left panel:__ Solid lines are multi-model global averages of surface warming (relative to 1980-1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. The orange line is for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely *range assessed for the six SRES marker scenarios at 2090-2099 relative to 1980-1999. The assessment of the best estimate and* likely *ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. __Right panels:__ Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020-2029 (left) and 2090-2099 (right). {WGI 10.4, 10.8, Figures 10.28, 10.29, SPM}*

Multi-model projected patterns of precipitation changes

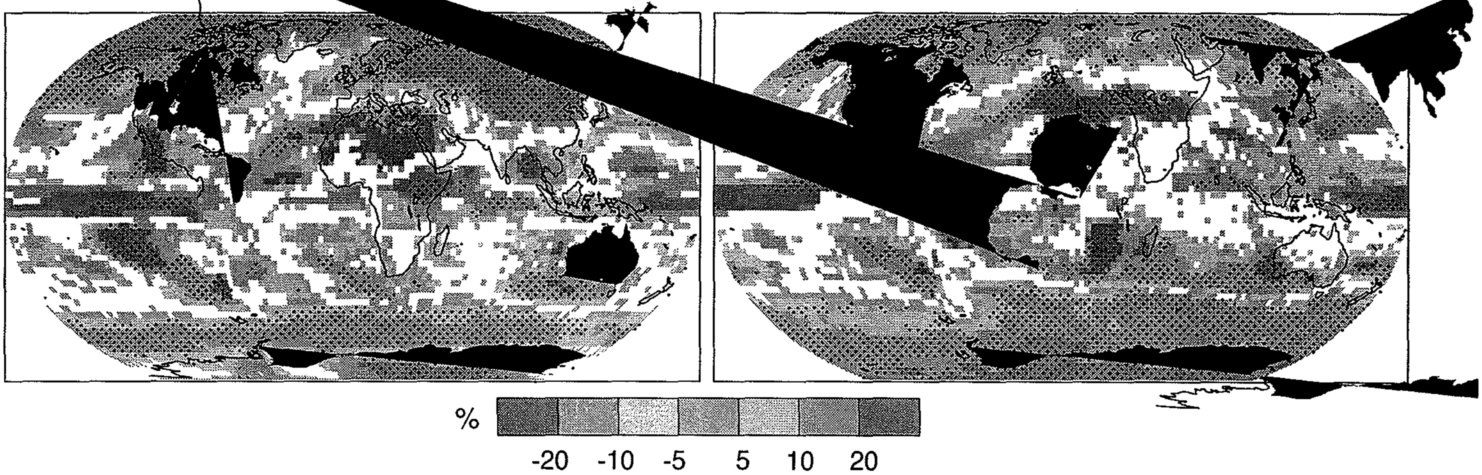

Figure 3.3. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {WGI Figure 10.9, SPM}

Contraction of the Greenland ice sheet is projected to continue to contribute to sea level rise after 2100. Current models suggest ice mass losses increase with temperature more rapidly than gains due to increased precipitation and that the surface mass balance becomes negative (net ice loss) at a global average warming (relative to pre-industrial values) in excess of 1.9 to 4.6°C. If such a negative surface mass balance were sustained for millennia, that would lead to virtually complete elimination of the Greenland ice sheet and a resulting contribution to sea level rise of about 7m. The corresponding future temperatures in Greenland (1.9 to 4.6°C global) are comparable to those inferred for the last interglacial period 125,000 years ago, when palaeoclimatic information suggests reductions of polar land ice extent and 4 to 6m of sea level rise. *{WGI 6.4, 10.7, SPM}*

Dynamical processes related to ice flow – which are not included in current models but suggested by recent observations – could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude. *{WGI 4.6, 10.7, SPM}*

Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance. *{WGI 10.7, SPM}*

Both past and future anthropogenic CO_2 emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of this gas from the atmosphere. *{WGI 7.3, 10.3, Figure 7.12, Figure 10.35, SPM}*

Estimated long-term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories is shown in Figure 3.4.

Estimated multi-century warming relative to 1980-1999 for AR4 stabilisation categories

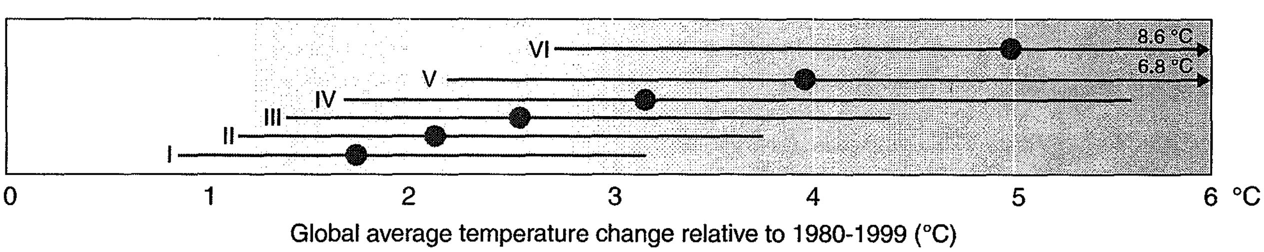

Figure 3.4. Estimated long-term (multi-century) warming corresponding to the six AR4 WG III stabilisation categories (Table 5.1). The temperature scale has been shifted by -0.5°C compared to Table 5.1 to account approximately for the warming between pre-industrial and 1980-1999. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For GHG emissions scenarios that lead to stabilisation at levels comparable to SRES B1 and A1B by 2100 (600 and 850 ppm CO_2-eq; category IV and V), assessed models project that about 65 to 70% of the estimated global equilibrium temperature increase, assuming a climate sensitivity of 3°C, would be realised at the time of stabilisation. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier. {WGI 10.7.2}

3.3 Impacts of future climate changes

More specific information is now available across a wide range of systems and sectors concerning the nature of future impacts, including some fields not covered in previous assessments. *{WGII TS.4, SPM}*

The following is a selection of key findings[14] regarding the impacts of climate change on systems, sectors and regions, as well as some findings on vulnerability[15], for the range of climate changes projected over the 21st century. Unless otherwise stated, the confidence level in the projections is *high*. Global average temperature increases are given relative to 1980-1999. Additional information on impacts can be found in the WG II report. *{WGII SPM}*

3.3.1 Impacts on systems and sectors

Ecosystems

- The resilience of many ecosystems is *likely* to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g. land-use change, pollution, fragmentation of natural systems, over-exploitation of resources). *{WGII 4.1-4.6, SPM}*
- Over the course of this century, net carbon uptake by terrestrial ecosystems is *likely* to peak before mid-century and then weaken or even reverse[16], thus amplifying climate change. *{WGII 4.ES, Figure 4.2, SPM}*
- Approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C (*medium confidence*). *{WGII 4.ES, Figure 4.2, SPM}*
- For increases in global average temperature exceeding 1.5 to 2.5°C and in concomitant atmospheric CO_2 concentrations, there are projected to be major changes in ecosystem structure and function, species' ecological interactions and shifts in species' geographical ranges, with predominantly negative consequences for biodiversity and ecosystem goods and services, e.g. water and food supply. *{WGII 4.4, Box TS.6, SPM}*

Food

- Crop productivity is projected to increase slightly at mid- to high latitudes for local mean temperature increases of up to 1 to 3°C depending on the crop, and then decrease beyond that in some regions (*medium confidence*). *{WGII 5.4, SPM}*
- At lower latitudes, especially in seasonally dry and tropical regions, crop productivity is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger (*medium confidence*). *{WGII 5.4, SPM}*
- Globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1 to 3°C, but above this it is projected to decrease (*medium confidence*). *{WGII 5.4, 5.5, SPM}*

Coasts

- Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise. The effect will be exacerbated by increasing human-induced pressures on coastal areas (*very high confidence*). *{WGII 6.3, 6.4, SPM}*
- By the 2080s, many millions more people than today are projected to experience floods every year due to sea level rise. The numbers affected will be largest in the densely populated and low-lying megadeltas of Asia and Africa while small islands are especially vulnerable (*very high confidence*). *{WGII 6.4, 6.5, Table 6.11, SPM}*

Industry, settlements and society

- The most vulnerable industries, settlements and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources and those in areas prone to extreme weather events, especially where rapid urbanisation is occurring. *{WGII 7.1, 7.3, 7.4, 7.5, SPM}*
- Poor communities can be especially vulnerable, in particular those concentrated in high-risk areas. *{WGII 7.2, 7.4, 5.4, SPM}*

Health

- The health status of millions of people is projected to be affected through, for example, increases in malnutrition; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal diseases; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some infectious diseases. *{WGI 7.4, Box 7.4; WGII 8.ES, 8.2, 8.4, SPM}*
- Climate change is projected to bring some benefits in temperate areas, such as fewer deaths from cold exposure, and some mixed effects such as changes in range and transmission potential of malaria in Africa. Overall it is expected that benefits will be outweighed by the negative health effects of rising temperatures, especially in developing countries. *{WGII 8.4, 8.7, 8ES, SPM}*
- Critically important will be factors that directly shape the health of populations such as education, health care, public health initiatives, and infrastructure and economic development. *{WGII 8.3, SPM}*

Water

- Water impacts are key for all sectors and regions. These are discussed below in the Box 'Climate change and water'.

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[14] Criteria of choice: magnitude and timing of impact, confidence in the assessment, representative coverage of the system, sector and region.

[15] Vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, adverse impacts.

[16] Assuming continued GHG emissions at or above current rates and other global changes including land-use changes.

Climate change and water

Climate change is expected to exacerbate current stresses on water resources from population growth and economic and land-use change, including urbanisation. On a regional scale, mountain snow pack, glaciers and small ice caps play a crucial role in freshwater availability. Widespread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydropower potential, and changing seasonality of flows in regions supplied by meltwater from major mountain ranges (e.g. Hindu-Kush, Himalaya, Andes), where more than one-sixth of the world population currently lives. *{WGI 4.1, 4.5; WGII 3.3, 3.4, 3.5}*

Changes in precipitation (Figure 3.3) and temperature (Figure 3.2) lead to changes in runoff (Figure 3.5) and water availability. Runoff is projected with *high confidence* to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, including populous areas in East and South-East Asia, and decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics, due to decreases in rainfall and higher rates of evapotranspiration. There is also *high confidence* that many semi-arid areas (e.g. the Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production and health. Regionally, large increases in irrigation water demand as a result of climate changes are projected. *{WGI 10.3, 11.2-11.9; WGII 3.4, 3.5, Figure 3.5, TS.4.1, Box TS.5, SPM}*

The negative impacts of climate change on freshwater systems outweigh its benefits (*high confidence*). Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources (*very high confidence*). The beneficial impacts of increased annual runoff in some areas are *likely* to be tempered by negative effects of increased precipitation variability and seasonal runoff shifts on water supply, water quality and flood risk. *{WGII 3.4, 3.5, TS.4.1}*

Available research suggests a significant future increase in heavy rainfall events in many regions, including some in which the mean rainfall is projected to decrease. The resulting increased flood risk poses challenges to society, physical infrastructure and water quality. It is *likely* that up to 20% of the world population will live in areas where river flood potential could increase by the 2080s. Increases in the frequency and severity of floods and droughts are projected to adversely affect sustainable development. Increased temperatures will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality. In coastal areas, sea level rise will exacerbate water resource constraints due to increased salinisation of groundwater supplies. *{WGI 11.2-11.9; WGII 3.2, 3.3, 3.4, 4.4}*

Projections and model consistency of relative changes in runoff by the end of the 21st century

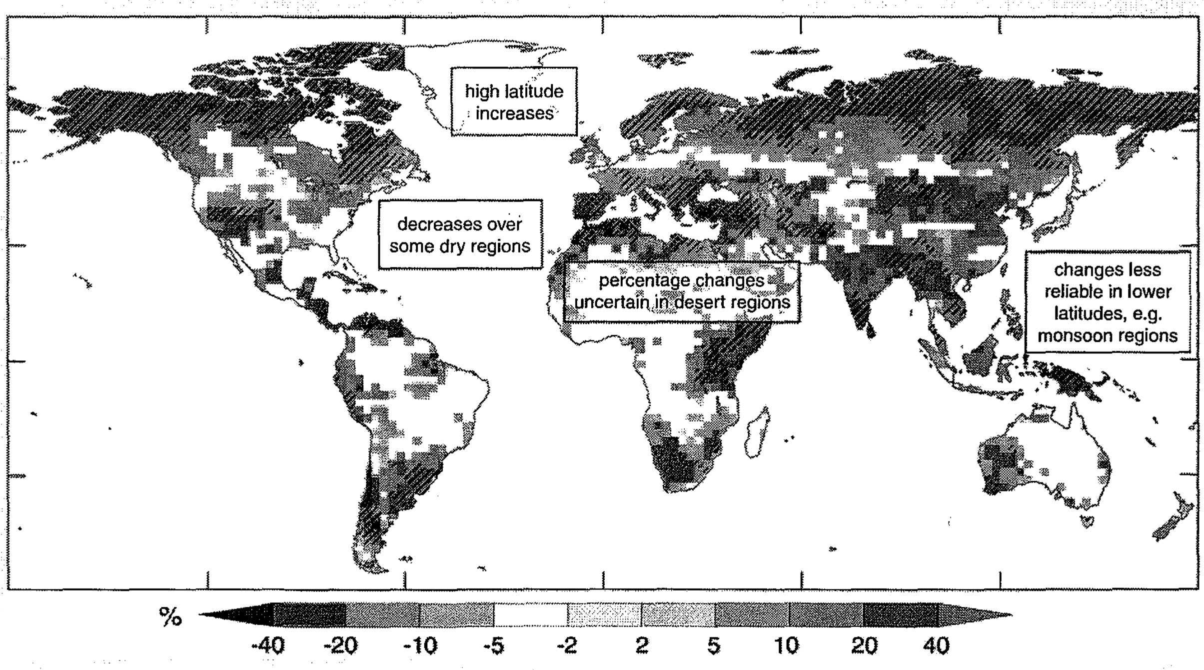


***Figure 3.5.** Large-scale relative changes in annual runoff (water availability, in percent) for the period 2090-2099, relative to 1980-1999. Values represent the median of 12 climate models using the SRES A1B scenario. White areas are where less than 66% of the 12 models agree on the sign of change and hatched areas are where more than 90% of models agree on the sign of change. The quality of the simulation of the observed large-scale 20th century runoff is used as a basis for selecting the 12 models from the multi-model ensemble. The global map of annual runoff illustrates a large scale and is not intended to refer to smaller temporal and spatial scales. In areas where rainfall and runoff is very low (e.g. desert areas), small changes in runoff can lead to large percentage changes. In some regions, the sign of projected changes in runoff differs from recently observed trends. In some areas with projected increases in runoff, different seasonal effects are expected, such as increased wet season runoff and decreased dry season runoff. Studies using results from few climate models can be considerably different from the results presented here. {WGII Figure 3.4, adjusted to match the assumptions of Figure SYR 3.3; WGII 3.3.1, 3.4.1, 3.5.1}*

Studies since the TAR have enabled more systematic understanding of the timing and magnitude of impacts related to differing amounts and rates of climate change. *{WGII SPM}*

Examples of this new information for systems and sectors are presented in Figure 3.6. The upper panel shows impacts increasing with increasing temperature change. Their estimated magnitude and timing is also affected by development pathways (lower panel). *{WGII SPM}*

Depending on circumstances, some of the impacts shown in Figure 3.6 could be associated with 'key vulnerabilities', based on a number of criteria in the literature (magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts) (see Topic 5.2). *{WGII SPM}*

3.3.2 Impacts on regions[17]

Africa

- By 2020, between 75 and 250 million of people are projected to be exposed to increased water stress due to climate change. *{WGII 9.4, SPM}*
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition. *{WGII 9.4, SPM}*
- Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of GDP. *{WGII 9.4, SPM}*
- By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (*high confidence*). *{WGII Box TS.6, 9.4.4}*

Asia

- By the 2050s, freshwater availability in Central, South, East and South-East Asia, particularly in large river basins, is projected to decrease. *{WGII 10.4, SPM}*
- Coastal areas, especially heavily populated megadelta regions in South, East and South-East Asia, will be at greatest risk due to increased flooding from the sea and, in some megadeltas, flooding from the rivers. *{WGII 10.4, SPM}*
- Climate change is projected to compound the pressures on natural resources and the environment associated with rapid urbanisation, industrialisation and economic development. *{WGII 10.4, SPM}*
- Endemic morbidity and mortality due to diarrhoeal disease primarily associated with floods and droughts are expected to rise in East, South and South-East Asia due to projected changes in the hydrological cycle. *{WGII 10.4, SPM}*

Australia and New Zealand

- By 2020, significant loss of biodiversity is projected to occur in some ecologically rich sites, including the Great Barrier Reef and Queensland Wet Tropics. *{WGII 11.4, SPM}*
- By 2030, water security problems are projected to intensify in southern and eastern Australia and, in New Zealand, in Northland and some eastern regions. *{WGII 11.4, SPM}*
- By 2030, production from agriculture and forestry is projected to decline over much of southern and eastern Australia, and over parts of eastern New Zealand, due to increased drought and fire. However, in New Zealand, initial benefits are projected in some other regions. *{WGII 11.4, SPM}*
- By 2050, ongoing coastal development and population growth in some areas of Australia and New Zealand are projected to exacerbate risks from sea level rise and increases in the severity and frequency of storms and coastal flooding. *{WGII 11.4, SPM}*

Europe

- Climate change is expected to magnify regional differences in Europe's natural resources and assets. Negative impacts will include increased risk of inland flash floods and more frequent coastal flooding and increased erosion (due to storminess and sea level rise). *{WGII 12.4, SPM}*
- Mountainous areas will face glacier retreat, reduced snow cover and winter tourism, and extensive species losses (in some areas up to 60% under high emissions scenarios by 2080). *{WGII 12.4, SPM}*
- In southern Europe, climate change is projected to worsen conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity. *{WGII 12.4, SPM}*
- Climate change is also projected to increase the health risks due to heat waves and the frequency of wildfires. *{WGII 12.4, SPM}*

Latin America

- By mid-century, increases in temperature and associated decreases in soil water are projected to lead to gradual replacement of tropical forest by savanna in eastern Amazonia. Semi-arid vegetation will tend to be replaced by arid-land vegetation. *{WGII 13.4, SPM}*
- There is a risk of significant biodiversity loss through species extinction in many areas of tropical Latin America. *{WGII 13.4, SPM}*
- Productivity of some important crops is projected to decrease and livestock productivity to decline, with adverse consequences for food security. In temperate zones, soybean yields are projected to increase. Overall, the number of people at risk of hunger is projected to increase (*medium confidence*). *{WGII 13.4, Box TS.6}*
- Changes in precipitation patterns and the disappearance of glaciers are projected to significantly affect water availability for human consumption, agriculture and energy generation. *{WGII 13.4, SPM}*

[17] Unless stated explicitly, all entries are from WG II SPM text, and are either *very high confidence* or *high confidence* statements, reflecting different sectors (agriculture, ecosystems, water, coasts, health, industry and settlements). The WG II SPM refers to the source of the statements, timelines and temperatures. The magnitude and timing of impacts that will ultimately be realised will vary with the amount and rate of climate change, emissions scenarios, development pathways and adaptation.

Examples of impacts associated with global average temperature change
(Impacts will vary by extent of adaptation, rate of temperature change and socio-economic pathway)

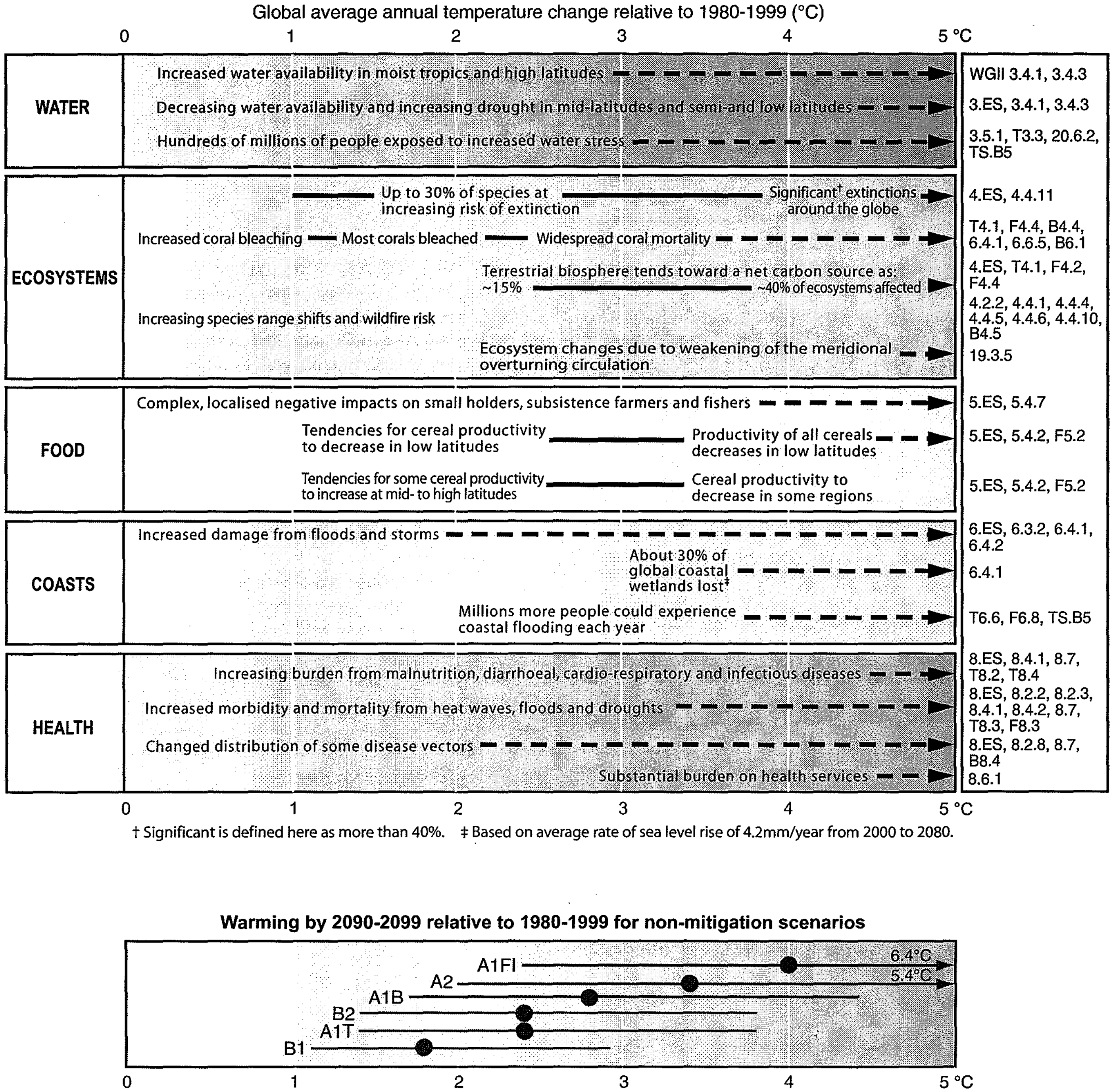


***Figure 3.6.** Examples of impacts associated with global average temperature change. **Upper panel:** Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are* high. *The upper right panel gives the WG II references for the statements made in the upper left panel.* **Lower panel:** Dots and bars indicate the best estimate and* likely *ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999. {WGI Figure SPM.5, 10.7; WGII Figure SPM.2; WGIII Table TS.2, Table 3.10}*

*Where ES = Executive Summary, T = Table, B = Box and F = Figure. Thus B4.5 indicates Box 4.5 in Chapter 4 and 3.5.1 indicates Section 3.5.1 in Chapter 3.

North America

- Warming in western mountains is projected to cause decreased snowpack, more winter flooding and reduced summer flows, exacerbating competition for over-allocated water resources. *{WGII 14.4, SPM}*
- In the early decades of the century, moderate climate change is projected to increase aggregate yields of rain-fed agriculture by 5 to 20%, but with important variability among regions. Major challenges are projected for crops that are near the warm end of their suitable range or which depend on highly utilised water resources. *{WGII 14.4, SPM}*
- Cities that currently experience heat waves are expected to be further challenged by an increased number, intensity and duration of heat waves during the course of the century, with potential for adverse health impacts. *{WGII 14.4, SPM}*
- Coastal communities and habitats will be increasingly stressed by climate change impacts interacting with development and pollution. *{WGII 14.4, SPM}*

Polar Regions

- The main projected biophysical effects are reductions in thickness and extent of glaciers, ice sheets and sea ice, and changes in natural ecosystems with detrimental effects on many organisms including migratory birds, mammals and higher predators. *{WGII 15.4, SPM}*
- For human communities in the Arctic, impacts, particularly those resulting from changing snow and ice conditions, are projected to be mixed. *{WGII 15.4, SPM}*
- Detrimental impacts would include those on infrastructure and traditional indigenous ways of life. *{WGII 15.4, SPM}*
- In both polar regions, specific ecosystems and habitats are projected to be vulnerable, as climatic barriers to species invasions are lowered. {WGII 15.4, SPM}

Small Islands

- Sea level rise is expected to exacerbate inundation, storm surge, erosion and other coastal hazards, thus threatening vital infrastructure, settlements and facilities that support the livelihood of island communities. *{WGII 16.4, SPM}*
- Deterioration in coastal conditions, for example through erosion of beaches and coral bleaching, is expected to affect local resources. *{WGII 16.4, SPM}*
- By mid-century, climate change is expected to reduce water resources in many small islands, e.g. in the Caribbean and Pacific, to the point where they become insufficient to meet demand during low-rainfall periods. *{WGII 16.4, SPM}*
- With higher temperatures, increased invasion by non-native species is expected to occur, particularly on mid- and high-latitude islands. *{WGII 16.4, SPM}*

3.3.3 Especially affected systems, sectors and regions

Some systems, sectors and regions are *likely* to be especially affected by climate change.[18] *{WGII TS.4.5}*

Systems and sectors: *{WGII TS.4.5}*

- particular ecosystems:
  - terrestrial: tundra, boreal forest and mountain regions because of sensitivity to warming; mediterranean-type ecosystems because of reduction in rainfall; and tropical rainforests where precipitation declines
  - coastal: mangroves and salt marshes, due to multiple stresses
  - marine: coral reefs due to multiple stresses; the sea-ice biome because of sensitivity to warming
- water resources in some dry regions at mid-latitudes[19] and in the dry tropics, due to changes in rainfall and evapotranspiration, and in areas dependent on snow and ice melt
- agriculture in low latitudes, due to reduced water availability
- low-lying coastal systems, due to threat of sea level rise and increased risk from extreme weather events
- human health in populations with low adaptive capacity.

Regions: *{WGII TS.4.5}*

- the Arctic, because of the impacts of high rates of projected warming on natural systems and human communities
- Africa, because of low adaptive capacity and projected climate change impacts
- small islands, where there is high exposure of population and infrastructure to projected climate change impacts
- Asian and African megadeltas, due to large populations and high exposure to sea level rise, storm surges and river flooding.

Within other areas, even those with high incomes, some people (such as the poor, young children and the elderly) can be particularly at risk, and also some areas and some activities. *{WGII 7.1, 7.2, 7.4, 8.2, 8.4, TS.4.5}*

3.3.4 Ocean acidification

The uptake of anthropogenic carbon since 1750 has led to the ocean becoming more acidic with an average decrease in pH of 0.1 units. Increasing atmospheric CO_2 concentrations lead to further acidification. Projections based on SRES scenarios give a reduction in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century. While the effects of observed ocean acidification on the marine biosphere are as yet undocumented, the progressive acidification of oceans is expected to have negative impacts on marine shell-forming organisms (e.g. corals) and their dependent species. *{WGI SPM; WGII SPM}*

3.3.5 Extreme events

Altered frequencies and intensities of extreme weather, together with sea level rise, are expected to have mostly adverse effects on natural and human systems (Table 3.2). *{WGII SPM}*

Examples for selected extremes and sectors are shown in Table 3.2.

[18] Identified on the basis of expert judgement of the assessed literature and considering the magnitude, timing and projected rate of climate change, sensitivity and adaptive capacity.

[19] Including arid and semi-arid regions.

Table 3.2. *Examples of possible impacts of climate change due to changes in extreme weather and climate events, based on projections to the mid- to late 21st century. These do not take into account any changes or developments in adaptive capacity. The likelihood estimates in column two relate to the phenomena listed in column one. {WGII Table SPM.1}*

Phenomenon[a] and direction of trend	Likelihood of future trends based on projections for 21st century using SRES scenarios	Examples of major projected impacts by sector			
		Agriculture, forestry and ecosystems *{WGII 4.4, 5.4}*	Water resources *{WGII 3.4}*	Human health *{WGII 8.2, 8.4}*	Industry, settlement and society *{WGII 7.4}*
Over most land areas, warmer and fewer cold days and nights, warmer and more frequent hot days and nights	*Virtually certain*[b]	Increased yields in colder environments; decreased yields in warmer environments; increased insect outbreaks	Effects on water resources relying on snowmelt; effects on some water supplies	Reduced human mortality from decreased cold exposure	Reduced energy demand for heating; increased demand for cooling; declining air quality in cities; reduced disruption to transport due to snow, ice; effects on winter tourism
Warm spells/heat waves. Frequency increases over most land areas	*Very likely*	Reduced yields in warmer regions due to heat stress; increased danger of wildfire	Increased water demand; water quality problems, e.g. algal blooms	Increased risk of heat-related mortality, especially for the elderly, chronically sick, very young and socially isolated	Reduction in quality of life for people in warm areas without appropriate housing; impacts on the elderly, very young and poor
Heavy precipitation events. Frequency increases over most areas	*Very likely*	Damage to crops; soil erosion, inability to cultivate land due to waterlogging of soils	Adverse effects on quality of surface and groundwater; contamination of water supply; water scarcity may be relieved	Increased risk of deaths, injuries and infectious, respiratory and skin diseases	Disruption of settlements, commerce, transport and societies due to flooding: pressures on urban and rural infrastructures; loss of property
Area affected by drought increases	*Likely*	Land degradation; lower yields/crop damage and failure; increased livestock deaths; increased risk of wildfire	More widespread water stress	Increased risk of food and water shortage; increased risk of malnutrition; increased risk of water- and food-borne diseases	Water shortage for settlements, industry and societies; reduced hydropower generation potentials; potential for population migration
Intense tropical cyclone activity increases	*Likely*	Damage to crops; windthrow (uprooting) of trees; damage to coral reefs	Power outages causing disruption of public water supply	Increased risk of deaths, injuries, water- and food-borne diseases; post-traumatic stress disorders	Disruption by flood and high winds; withdrawal of risk coverage in vulnerable areas by private insurers; potential for population migrations; loss of property
Increased incidence of extreme high sea level (excludes tsunamis)[c]	*Likely*[d]	Salinisation of irrigation water, estuaries and fresh-water systems	Decreased fresh-water availability due to saltwater intrusion	Increased risk of deaths and injuries by drowning in floods; migration-related health effects	Costs of coastal protection versus costs of land-use relocation; potential for movement of populations and infrastructure; also see tropical cyclones above

Notes:
a) See WGI Table 3.7 for further details regarding definitions.
b) Warming of the most extreme days and nights each year.
c) Extreme high sea level depends on average sea level and on regional weather systems. It is defined as the highest 1% of hourly values of observed sea level at a station for a given reference period.
d) In all scenarios, the projected global average sea level at 2100 is higher than in the reference period. The effect of changes in regional weather systems on sea level extremes has not been assessed. *{WGI 10.6}*

3.4 Risk of abrupt or irreversible changes

Anthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change. ***{WGII 12.6, 19.3, 19.4, SPM}***

Abrupt climate change on decadal time scales is normally thought of as involving ocean circulation changes. In addition on longer time scales, ice sheet and ecosystem changes may also play a role. If a large-scale abrupt climate change were to occur, its impact could be quite high (see Topic 5.2). *{WGI 8.7, 10.3, 10.7; WGII 4.4, 19.3}*

Partial loss of ice sheets on polar land and/or the thermal expansion of seawater over very long time scales could imply metres of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Current models project that such changes would occur over very long time scales (millennial) if a global temperature increase of 1.9 to 4.6°C (relative to pre-industrial) were to be sustained. Rapid sea level rise on century time scales cannot be excluded. *{SYR 3.2.3; WGI 6.4, 10.7; WGII 19.3, SPM}*

Climate change is *likely* to lead to some irreversible impacts. There is *medium confidence* that approximately 20 to 30% of species assessed so far are *likely* to be at increased risk of extinction if increases in global average warming exceed 1.5 to 2.5°C (relative to 1980-1999). As global average temperature increase exceeds about 3.5°C, model projections suggest significant extinctions (40 to 70% of species assessed) around the globe. *{WGII 4.4, Figure SPM.2}*

Based on current model simulations, it is *very likely* that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century; nevertheless temperatures in the region are projected to increase. It is *very unlikely* that the MOC will undergo a large abrupt transition during the 21st century. Longer-term changes in the MOC cannot be assessed with confidence. *{WGI 10.3, 10.7; WGII Figure, Table TS.5, SPM.2}*

Impacts of large-scale and persistent changes in the MOC are *likely* to include changes in marine ecosystem productivity, fisheries, ocean CO_2 uptake, oceanic oxygen concentrations and terrestrial vegetation. Changes in terrestrial and ocean CO_2 uptake may feed back on the climate system. *{WGII 12.6, 19.3, Figure SPM.2}*

4

Adaptation and mitigation options and responses, and the inter-relationship with sustainable development, at global and regional levels

4.1 Responding to climate change

Societies can respond to climate change by adapting to its impacts and by reducing GHG emissions (mitigation), thereby reducing the rate and magnitude of change. This Topic focuses on adaptation and mitigation options that can be implemented over the next two to three decades, and their inter-relationship with sustainable development. These responses can be complementary. Topic 5 addresses their complementary roles on a more conceptual basis over a longer timeframe.

The capacity to adapt and mitigate is dependent on socio-economic and environmental circumstances and the availability of information and technology[20]. However, much less information is available about the costs and effectiveness of adaptation measures than about mitigation measures. *{WGII 17.1, 17.3; WGIII 1.2}*

4.2 Adaptation options

Adaptation can reduce vulnerability, both in the short and the long term. ***{WGII 17.2, 18.1, 18.5, 20.3, 20.8}***

Vulnerability to climate change can be exacerbated by other stresses. These arise from, for example, current climate hazards, poverty, unequal access to resources, food insecurity, trends in economic globalisation, conflict and incidence of diseases such as HIV/AIDS. *{WGII 7.2, 7.4, 8.3, 17.3, 20.3, 20.4, 20.7, SPM}*

Societies across the world have a long record of adapting and reducing their vulnerability to the impacts of weather- and climate-related events such as floods, droughts and storms. Nevertheless, additional adaptation measures will be required at regional and local levels to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades. However, adaptation alone is not expected to cope with all the projected effects of climate change, especially not over the long term as most impacts increase in magnitude. *{WGII 17.2, SPM; WGIII 1.2}*

A wide array of adaptation options is available, but more extensive adaptation than is currently occurring is required to reduce vulnerability to climate change. There are barriers, limits and costs, which are not fully understood. Some planned adaptation is already occurring on a limited basis. Table 4.1 provides examples of planned adaptation options by sector. Many adaptation actions have multiple drivers, such as economic development and poverty alleviation, and are embedded within broader development, sectoral, regional and local planning initiatives such as water resources planning, coastal defence and disaster risk reduction strategies. Examples of this approach are the Bangladesh National Water Management Plan and the coastal defence plans of The Netherlands and Norway, which incorporate specific climate change scenarios. *{WGII 1.3, 5.5.2, 11.6, 17.2}*

Comprehensive estimates of the costs and benefits of adaptation at the global level are limited in number. However, the number of adaptation cost and benefit estimates at the regional and project levels for impacts on specific sectors, such as agriculture, energy demand for heating and cooling, water resources management and infrastructure, is growing. Based on these studies there is *high confidence* that there are viable adaptation options that can be implemented in some of these sectors at low cost and/or with high benefit-cost ratios. Empirical research also suggests that higher benefit-cost ratios can be achieved by implementing some adaptation measures at an early stage compared to retrofitting long-lived infrastructure at a later date. *{WGII 17.2}*

Adaptive capacity is intimately connected to social and economic development, but it is not evenly distributed across and within societies. ***{WGII 7.1, 7.2, 7.4, 17.3}***

The capacity to adapt is dynamic and is influenced by a society's productive base, including natural and man-made capital assets, social networks and entitlements, human capital and institutions, governance, national income, health and technology. It is also affected by multiple climate and non-climate stresses, as well as development policy. *{WGII 17.3}*

Recent studies reaffirm the TAR finding that adaptation will be vital and beneficial. However, financial, technological, cognitive, behavioural, political, social, institutional and cultural constraints limit both the implementation and effectiveness of adaptation measures. Even societies with high adaptive capacity remain vulnerable to climate change, variability and extremes. For example, a heat wave in 2003 caused high levels of mortality in European cities (especially among the elderly), and Hurricane Katrina in 2005 caused large human and financial costs in the United States. *{WGII 7.4, 8.2, 17.4}*

[20] Technology is defined as the practical application of knowledge to achieve particular tasks that employs both technical artefacts (hardware, equipment) and (social) information ('software', know-how for production and use of artefacts).

Table 4.1. Selected examples of planned adaptation by sector.

Sector	Adaptation option/strategy	Underlying policy framework	Key constraints and opportunities to implementation (Normal font = constraints; *italics = opportunities*)
Water {WGII, 5.5, 16.4; Tables 3.5, 11.6,17.1}	Expanded rainwater harvesting; water storage and conservation techniques; water reuse; desalination; water-use and irrigation efficiency	National water policies and integrated water resources management; water-related hazards management	Financial, human resources and physical barriers; *integrated water resources management; synergies with other sectors*
Agriculture {WGII 10.5, 13.5; Table 10.8}	Adjustment of planting dates and crop variety; crop relocation; improved land management, e.g. erosion control and soil protection through tree planting	R&D policies; institutional reform; land tenure and land reform; training; capacity building; crop insurance; financial incentives, e.g. subsidies and tax credits	Technological and financial constraints; access to new varieties; markets; *longer growing season in higher latitudes; revenues from 'new' products*
Infrastructure/ settlement (including coastal zones) {WGII 3.6, 11.4; Tables 6.11, 17.1}	Relocation; seawalls and storm surge barriers; dune reinforcement; land acquisition and creation of marshlands/wetlands as buffer against sea level rise and flooding; protection of existing natural barriers	Standards and regulations that integrate climate change considerations into design; land-use policies; building codes; insurance	Financial and technological barriers; availability of relocation space; *integrated policies and management; synergies with sustainable development goals*
Human health {WGII 14.5, Table 10.8}	Heat-health action plans; emergency medical services; improved climate-sensitive disease surveillance and control; safe water and improved sanitation	Public health policies that recognise climate risk; strengthen health services; regional and international cooperation	Limits to human tolerance (vulnerable groups); knowledge limitations; financial capacity; *upgraded health services; improved quality of life*
Tourism {WGII 12.5, 15.5, 17.5; Table 17.1}	Diversification of tourism attractions and revenues; shifting ski slopes to higher altitudes and glaciers; artificial snow-making	Integrated planning (e.g. carrying capacity; linkages with other sectors); financial incentives, e.g. subsidies and tax credits	Appeal/marketing of new attractions; financial and logistical challenges; potential adverse impact on other sectors (e.g. artificial snow-making may increase energy use); *revenues from 'new' attractions; involvement of wider group of stakeholders*
Transport {WGII 7.6, 17.2}	Realignment/relocation; design standards and planning for roads, rail and other infrastructure to cope with warming and drainage	Integrating climate change considerations into national transport policy; investment in R&D for special situations, e.g. permafrost areas	Financial and technological barriers; availability of less vulnerable routes; *improved technologies and integration with key sectors (e.g. energy)*
Energy {WGII 7.4, 16.2}	Strengthening of overhead transmission and distribution infrastructure; underground cabling for utilities; energy efficiency; use of renewable sources; reduced dependence on single sources of energy	National energy policies, regulations, and fiscal and financial incentives to encourage use of alternative sources; incorporating climate change in design standards	Access to viable alternatives; financial and technological barriers; acceptance of new technologies; *stimulation of new technologies; use of local resources*

Note:
Other examples from many sectors would include early warning systems.

4.3 Mitigation options

Both bottom-up and top-down studies[21] indicate that there is *high agreement* and *much evidence* of substantial economic potential[21] for the mitigation of global GHG emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels. *{WGIII 11.3, SPM}*

Figure 4.1 compares global economic mitigation potential in 2030 with the projected emissions increase from 2000 to 2030. Bottom-up studies suggest that mitigation opportunities with net negative costs[22] have the potential to reduce emissions by about 6 $GtCO_2$-eq/yr in 2030. Realising these requires dealing with implementation barriers. The economic mitigation potential, which is generally greater than the market mitigation potential, can only be achieved when adequate policies are in place and barriers removed.[21] *{WGIII 11.3, SPM}*

Sectoral estimates of economic mitigation potential and marginal costs derived from bottom-up studies corrected for double counting of mitigation potential are shown in Figure 4.2. While top-down and bottom-up studies are in line at the global level, there are considerable differences at the sectoral level. *{WGIII 11.3, SPM}*

No single technology can provide all of the mitigation potential in any sector. Table 4.2 lists selected examples of key technologies, policies, constraints and opportunities by sector. *{WGIII SPM}*

Future energy infrastructure investment decisions, expected to total over US$20 trillion[23] between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO_2 emissions to 2005 levels by 2030 would require a large shift in the pattern of investment, although the net additional investment required ranges from negligible to 5 to 10%. *{WGIII 4.1, 4.4, 11.6, SPM}*

Comparison between global economic mitigation potential and projected emissions increase in 2030

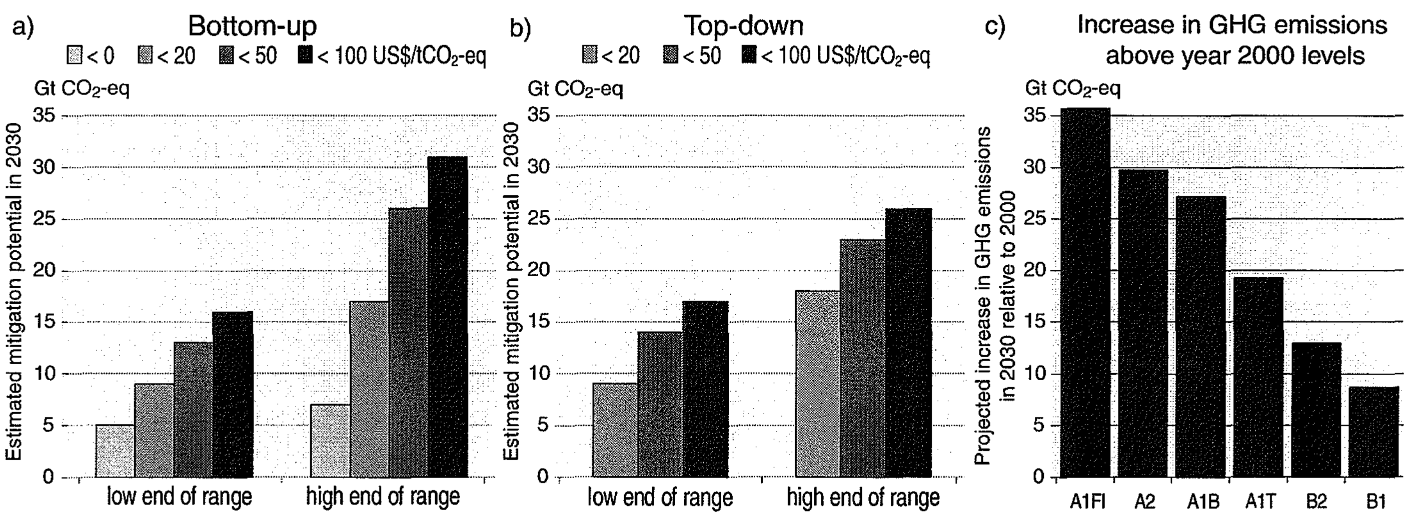


Figure 4.1. *Global economic mitigation potential in 2030 estimated from bottom-up (Panel a) and top-down (Panel b) studies, compared with the projected emissions increases from SRES scenarios relative to year 2000 GHG emissions of 40.8 $GtCO_2$-eq (Panel c). Note: GHG emissions in 2000 are exclusive of emissions of decay of above-ground biomass that remains after logging and deforestation and from peat fires and drained peat soils, to ensure consistency with the SRES emissions results. {WGIII Figures SPM.4, SPM.5a, SPM.5b}*

[21] The concept of **'mitigation potential'** has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced). Mitigation potential is further differentiated in terms of 'market mitigation potential' and 'economic mitigation potential'.

Market mitigation potential is the mitigation potential based on private costs and private discount rates (reflecting the perspective of private consumers and companies), which might be expected to occur under forecast market conditions, including policies and measures currently in place, noting that barriers limit actual uptake.

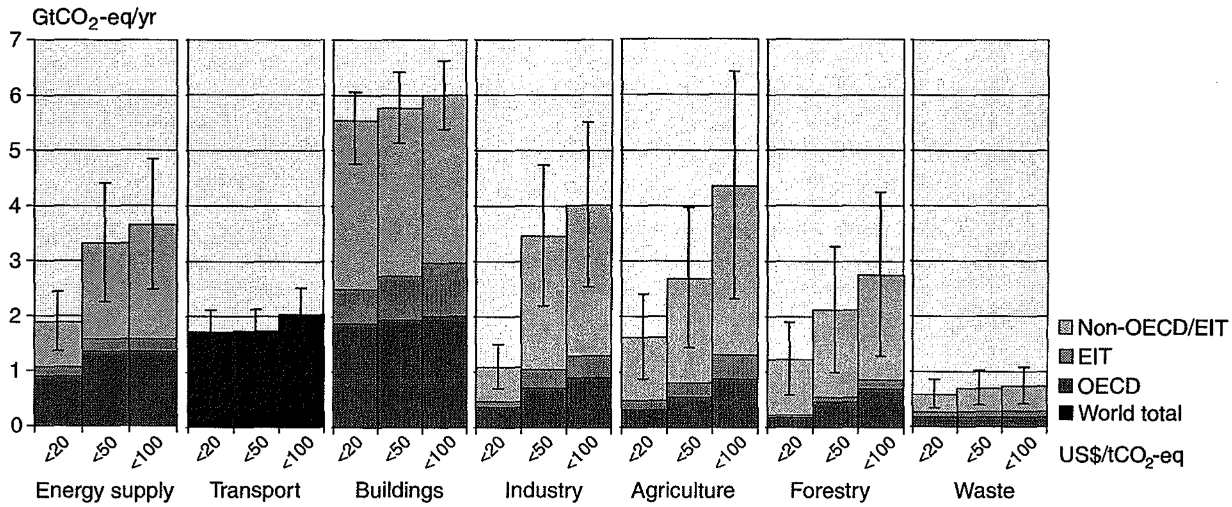
Economic mitigation potential is the mitigation potential that takes into account social costs and benefits and social discount rates (reflecting the perspective of society; social discount rates are lower than those used by private investors), assuming that market efficiency is improved by policies and measures and barriers are removed.

Mitigation potential is estimated using different types of approaches. ***Bottom-up studies*** are based on assessment of mitigation options, emphasising specific technologies and regulations. They are typically sectoral studies taking the macro-economy as unchanged. ***Top-down studies*** assess the economy-wide potential of mitigation options. They use globally consistent frameworks and aggregated information about mitigation options and capture macro-economic and market feedbacks.

[22] Net negative costs (no regrets opportunities) are defined as those options whose benefits such as reduced energy costs and reduced emissions of local/regional pollutants equal or exceed their costs to society, excluding the benefits of avoided climate change.

[23] 20 trillion = 20,000 billion = 20×10^{12}

Economic mitigation potentials by sector in 2030 estimated from bottom-up studies



total sectoral potential at <US$100/tCO$_2$-eq in GtCO$_2$-eq/yr:

Energy supply	Transport	Buildings	Industry	Agriculture	Forestry	Waste
2.4-4.7	1.6-2.5	5.3-6.7	2.5-5.5	2.3-6.4	1.3-4.2	0.4-1.0

Figure 4.2. *Estimated economic mitigation potential by sector and region using technologies and practices expected to be available in 2030. The potentials do not include non-technical options such as lifestyle changes. {WGIII Figure SPM.6}*

Notes:

a) The ranges for global economic potentials as assessed in each sector are shown by vertical lines. The ranges are based on end-use allocations of emissions, meaning that emissions of electricity use are counted towards the end-use sectors and not to the energy supply sector.
b) The estimated potentials have been constrained by the availability of studies particularly at high carbon price levels.
c) Sectors used different baselines. For industry the SRES B2 baseline was taken, for energy supply and transport the World Energy Outlook (WEO) 2004 baseline was used; the building sector is based on a baseline in between SRES B2 and A1B; for waste, SRES A1B driving forces were used to construct a waste-specific baseline; agriculture and forestry used baselines that mostly used B2 driving forces.
d) Only global totals for transport are shown because international aviation is included.
e) Categories excluded are non-CO$_2$ emissions in buildings and transport, part of material efficiency options, heat production and cogeneration in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%.

While studies use different methodologies, there is *high agreement* and *much evidence* that in all analysed world regions near-term health co-benefits from reduced air pollution, as a result of actions to reduce GHG emissions, can be substantial and may offset a substantial fraction of mitigation costs. ***{WGIII 11.8, SPM}***

Energy efficiency and utilisation of renewable energy offer synergies with sustainable development. In least developed countries, energy substitution can lower mortality and morbidity by reducing indoor air pollution, reduce the workload for women and children and decrease the unsustainable use of fuelwood and related deforestation. *{WGIII 11.8, 11.9, 12.4}*

Literature since the TAR confirms with *high agreement* and *medium evidence* that there may be effects from Annex I countries' action on the global economy and global emissions, although the scale of carbon leakage remains uncertain. ***{WGIII 11.7, SPM}***

Fossil fuel exporting nations (in both Annex I and non-Annex I countries) may expect, as indicated in the TAR, lower demand and prices and lower GDP growth due to mitigation policies. The extent of this spillover depends strongly on assumptions related to policy decisions and oil market conditions. *{WGIII 11.7, SPM}*

Critical uncertainties remain in the assessment of carbon leakage. Most equilibrium modelling supports the conclusion in the TAR of economy-wide leakage from Kyoto action in the order of 5 to 20%, which would be less if competitive low-emissions technologies were effectively diffused. *{WGIII 11.7, SPM}*

There is also *high agreement* and *medium evidence* that changes in lifestyle and behaviour patterns can contribute to climate change mitigation across all sectors. Management practices can also have a positive role. ***{WGIII SPM}***

Examples that can have positive impacts on mitigation include changes in consumption patterns, education and training, changes in building occupant behaviour, transport demand management and management tools in industry. *{WGIII 4.1, 5.1, 6.7, 7.3, SPM}*

Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-GHG products, technologies and processes. ***{WGIII SPM}***

An effective carbon-price signal could realise significant mitigation potential in all sectors. Modelling studies show that global carbon prices rising to US$20-80/tCO$_2$-eq by 2030 are consistent with stabilisation at around 550ppm CO$_2$-eq by 2100. For the same

Table 4.2 *Selected examples of key sectoral mitigation technologies, policies and measures, constraints and opportunities. {WGIII Tables SPM.3, SPM.7}*

Sector	Key mitigation technologies and practices currently commercially available. *Key mitigation technologies and practices projected to be commercialised before 2030 shown in italics.*	Policies, measures and instruments shown to be environmentally effective	Key constraints or opportunities (Normal font = constraints; *italics = opportunities*)
Energy Supply {WGIII 4.3, 4.4}	Improved supply and distribution efficiency; fuel switching from coal to gas; nuclear power; renewable heat and power (hydropower, solar, wind, geothermal and bioenergy); combined heat and power; early applications of carbon dioxide capture and storage (CCS) (e.g. storage of removed CO_2 from natural gas); *CCS for gas, biomass and coal-fired electricity generating facilities; advanced nuclear power; advanced renewable energy, including tidal and wave energy, concentrating solar, and solar photovoltaics*	Reduction of fossil fuel subsidies; taxes or carbon charges on fossil fuels	Resistance by vested interests may make them difficult to implement
		Feed-in tariffs for renewable energy technologies; renewable energy obligations; producer subsidies	*May be appropriate to create markets for low-emissions technologies*
Transport {WGIII 5.4}	More fuel-efficient vehicles; hybrid vehicles; cleaner diesel vehicles; biofuels; modal shifts from road transport to rail and public transport systems; non-motorised transport (cycling, walking); land-use and transport planning; *second generation biofuels; higher efficiency aircraft; advanced electric and hybrid vehicles with more powerful and reliable batteries*	Mandatory fuel economy; biofuel blending and CO_2 standards for road transport	Partial coverage of vehicle fleet may limit effectiveness
		Taxes on vehicle purchase, registration, use and motor fuels; road and parking pricing	Effectiveness may drop with higher incomes
		Influence mobility needs through land-use regulations and infrastructure planning; investment in attractive public transport facilities and non-motorised forms of transport	*Particularly appropriate for countries that are building up their transportation systems*
Buildings {WGIII 6.5}	Efficient lighting and daylighting; more efficient electrical appliances and heating and cooling devices; improved cook stoves, improved insulation; passive and active solar design for heating and cooling; alternative refrigeration fluids, recovery and recycling of fluorinated gases; *integrated design of commercial buildings including technologies, such as intelligent meters that provide feedback and control; solar photovoltaics integrated in buildings*	Appliance standards and labelling	Periodic revision of standards needed
		Building codes and certification	*Attractive for new buildings.* Enforcement can be difficult
		Demand-side management programmes	Need for regulations so that utilities may profit
		Public sector leadership programmes, including procurement	*Government purchasing can expand demand for energy-efficient products*
		Incentives for energy service companies (ESCOs)	*Success factor: Access to third party financing*
Industry {WGIII 7.5}	More efficient end-use electrical equipment; heat and power recovery; material recycling and substitution; control of non-CO_2 gas emissions; and a wide array of process-specific technologies; *advanced energy efficiency; CCS for cement, ammonia, and iron manufacture; inert electrodes for aluminium manufacture*	Provision of benchmark information; performance standards; subsidies; tax credits	*May be appropriate to stimulate technology uptake.* Stability of national policy important in view of international competitiveness
		Tradable permits	Predictable allocation mechanisms and stable price signals important for investments
		Voluntary agreements	Success factors include: clear targets, a baseline scenario, third-party involvement in design and review and formal provisions of monitoring, close cooperation between government and industry
Agriculture {WGIII 8.4}	Improved crop and grazing land management to increase soil carbon storage; restoration of cultivated peaty soils and degraded lands; improved rice cultivation techniques and livestock and manure management to reduce CH_4 emissions; improved nitrogen fertiliser application techniques to reduce N_2O emissions; dedicated energy crops to replace fossil fuel use; improved energy efficiency; *improvements of crop yields*	Financial incentives and regulations for improved land management; maintaining soil carbon content; efficient use of fertilisers and irrigation	*May encourage synergy with sustainable development and with reducing vulnerability to climate change, thereby overcoming barriers to implementation*
Forestry/forests {WGIII 9.4}	Afforestation; reforestation; forest management; reduced deforestation; harvested wood product management; use of forestry products for bioenergy to replace fossil fuel use; *tree species improvement to increase biomass productivity and carbon sequestration; improved remote sensing technologies for analysis of vegetation/soil carbon sequestration potential and mapping land-use change*	Financial incentives (national and international) to increase forest area, to reduce deforestation and to maintain and manage forests; land-use regulation and enforcement	Constraints include lack of investment capital and land tenure issues. *Can help poverty alleviation.*
Waste {WGIII 10.4}	Landfill CH_4 recovery; waste incineration with energy recovery; composting of organic waste; controlled wastewater treatment; recycling and waste minimisation; *biocovers and biofilters to optimise CH_4 oxidation*	Financial incentives for improved waste and wastewater management	*May stimulate technology diffusion*
		Renewable energy incentives or obligations	Local availability of low-cost fuel
		Waste management regulations	Most effectively applied at national level with enforcement strategies

stabilisation level, studies since the TAR that take into account induced technological change may lower these price ranges to US$5-65/t$CO_2$-eq in 2030.[24] *{WGIII 3.3, 11.4, 11.5, SPM}*

There is *high agreement* and *much evidence* that a wide variety of national policies and instruments are available to governments to create the incentives for mitigation action. Their applicability depends on national circumstances and an understanding of their interactions, but experience from implementation in various countries and sectors shows there are advantages and disadvantages for any given instrument. ***{WGIII 13.2, SPM}***

Four main criteria are used to evaluate policies and instruments: environmental effectiveness, cost effectiveness, distributional effects including equity, and institutional feasibility. *{WGIII 13.2, SPM}*

General findings about the performance of policies are: *{WGIII 13.2, SPM}*

- ***Integrating climate policies in broader development policies*** makes implementation and overcoming barriers easier.
- ***Regulations and standards*** generally provide some certainty about emission levels. They may be preferable to other instruments when information or other barriers prevent producers and consumers from responding to price signals. However, they may not induce innovations and more advanced technologies.
- ***Taxes and charges*** can set a price for carbon, but cannot guarantee a particular level of emissions. Literature identifies taxes as an efficient way of internalising costs of GHG emissions.
- ***Tradable permits*** will establish a carbon price. The volume of allowed emissions determines their environmental effectiveness, while the allocation of permits has distributional consequences. Fluctuation in the price of carbon makes it difficult to estimate the total cost of complying with emission permits.
- ***Financial incentives*** (subsidies and tax credits) are frequently used by governments to stimulate the development and diffusion of new technologies. While economic costs are generally higher than for the instruments listed above, they are often critical to overcome barriers.
- ***Voluntary agreements*** between industry and governments are politically attractive, raise awareness among stakeholders and have played a role in the evolution of many national policies. The majority of agreements have not achieved significant emissions reductions beyond business as usual. However, some recent agreements, in a few countries, have accelerated the application of best available technology and led to measurable emission reductions.
- ***Information instruments*** (e.g. awareness campaigns) may positively affect environmental quality by promoting informed choices and possibly contributing to behavioural change, however, their impact on emissions has not been measured yet.
- ***Research, development and demonstration (RD&D)*** can stimulate technological advances, reduce costs and enable progress toward stabilisation.

Some corporations, local and regional authorities, NGOs and civil groups are adopting a wide variety of voluntary actions. These voluntary actions may limit GHG emissions, stimulate innovative policies and encourage the deployment of new technologies. On their own, they generally have limited impact on national- or regional-level emissions. *{WGIII 13.4, SPM}*

4.4 Relationship between adaptation and mitigation options and relationship with sustainable development

There is growing understanding of the possibilities to choose and implement climate response options in several sectors to realise synergies and avoid conflicts with other dimensions of sustainable development. ***{WGIII SPM}***

Climate change policies related to energy efficiency and renewable energy are often economically beneficial, improve energy security and reduce local pollutant emissions. Reducing both loss of natural habitat and deforestation can have significant biodiversity, soil and water conservation benefits, and can be implemented in a socially and economically sustainable manner. Forestation and bioenergy plantations can restore degraded land, manage water runoff, retain soil carbon and benefit rural economies, but could compete with food production and may be negative for biodiversity, if not properly designed. *{WGII 20.3, 20.8; WGIII 4.5, 9.7, 12.3, SPM}*

There is growing evidence that decisions about macro-economic policy, agricultural policy, multilateral development bank lending, insurance practices, electricity market reform, energy security and forest conservation, for example, which are often treated as being apart from climate policy, can significantly reduce emissions (Table 4.3). Similarly, non-climate policies can affect adaptive capacity and vulnerability. *{WGII 20.3; WGIII SPM, 12.3}*

Both synergies and trade-offs exist between adaptation and mitigation options. ***{WGII 18.4.3; WGIII 11.9)***

Examples of synergies include properly designed biomass production, formation of protected areas, land management, energy use in buildings, and forestry, but synergies are rather limited in other sectors. Potential trade-offs include increased GHG emissions due to increased consumption of energy related to adaptive responses. *{WGII 18.4.3, 18.5, 18.7, TS.5.2; WGIII 4.5, 6.9, 8.5, 9.5, SPM}*

[24] Studies on mitigation portfolios and macro-economic costs assessed in this report are based on top-down modelling. Most models use a global least-cost approach to mitigation portfolios, with universal emissions trading, assuming transparent markets, no transaction cost, and thus perfect implementation of mitigation measures throughout the 21st century. Costs are given for a specific point in time. Global modelled costs will increase if some regions, sectors (e.g. land use), options or gases are excluded. Global modelled costs will decrease with lower baselines, use of revenues from carbon taxes and auctioned permits, and if induced technological learning is included. These models do not consider climate benefits and generally also co-benefits of mitigation measures, or equity issues. Significant progress has been achieved in applying approaches based on induced technological change to stabilisation studies; however, conceptual issues remain. In the models that consider induced technological change, projected costs for a given stabilisation level are reduced; the reductions are greater at lower stabilisation level.

Table 4.3. *Integrating climate change considerations into development policies – selected examples in the area of mitigation. {WGIII 12.2.4.6}*

Selected sectors	Non-climate change policy instruments and actions	Potentially affects:
Macro-economy	Implement non-climate taxes/subsidies and/or other fiscal and regulatory policies that promote sustainable development	Total global GHG emissions
Forestry	Adoption of forest conservation and sustainable management practices	GHG emissions from deforestation
Electricity	Adoption of cost-effective renewables, demand-side management programmes, and transmission and distribution loss reduction	Electricity sector CO_2 emissions
Petroleum imports	Diversifying imported and domestic fuel mix and reducing economy's energy intensity to improve energy security	Emissions from crude oil and product imports
Insurance for building, transport sectors	Differentiated premiums, liability insurance exclusions, improved terms for green products	Transport and building sector GHG emissions
International finance	Country and sector strategies and project lending that reduces emissions	Emissions from developing countries

4.5 International and regional cooperation

There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to the climate change problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation efforts. Progress has also been made in addressing adaptation within the UNFCCC and additional initiatives have been suggested. ***{WGII 18.7; WGIII 13.3, SPM}***

The impact of the Protocol's first commitment period relative to global emissions is projected to be limited. Its economic impacts on participating Annex-B countries are projected to be smaller than presented in the TAR, which showed 0.2 to 2% lower GDP in 2012 without emissions trading and 0.1 to 1.1% lower GDP with emissions trading among Annex-B countries. To be more environmentally effective, future mitigation efforts would need to achieve deeper reductions covering a higher share of global emissions (see Topic 5). *{WGIII 1.4, 11.4, 13.3, SPM}*

The literature provides *high agreement* and *much evidence* of many options for achieving reductions of global GHG emissions at the international level through cooperation. It also suggests that successful agreements are environmentally effective, cost-effective, incorporate distributional considerations and equity, and are institutionally feasible. ***{WGIII 13.3, SPM}***

Greater cooperative efforts to reduce emissions will help to reduce global costs for achieving a given level of mitigation, or will improve environmental effectiveness. Improving and expanding the scope of market mechanisms (such as emission trading, Joint Implementation and Clean Development Mechanism) could reduce overall mitigation costs. *{WGIII 13.3, SPM}*

Efforts to address climate change can include diverse elements such as emissions targets; sectoral, local, sub-national and regional actions; RD&D programmes; adopting common policies; implementing development-oriented actions; or expanding financing instruments. These elements can be implemented in an integrated fashion, but comparing the efforts made by different countries quantitatively would be complex and resource intensive. *{WGIII 13.3, SPM}*

Actions that could be taken by participating countries can be differentiated both in terms of when such action is undertaken, who participates and what the action will be. Actions can be binding or non-binding, include fixed or dynamic targets, and participation can be static or vary over time. *{WGIII 13.3, SPM}*

5

The long-term perspective: scientific and socio-economic aspects relevant to adaptation and mitigation, consistent with the objectives and provisions of the Convention, and in the context of sustainable development

5.1 Risk management perspective

Responding to climate change involves an iterative risk management process that includes both mitigation and adaptation, taking into account actual and avoided climate change damages, co-benefits, sustainability, equity and attitudes to risk. *{WGII 20. 9, SPM; WGIII SPM}*

Risk management techniques can explicitly accommodate sectoral, regional and temporal diversity, but their application requires information about not only impacts resulting from the most likely climate scenarios, but also impacts arising from lower-probability but higher-consequence events and the consequences of proposed policies and measures. Risk is generally understood to be the product of the likelihood of an event and its consequences. Climate change impacts depend on the characteristics of natural and human systems, their development pathways and their specific locations. *{SYR 3.3, Figure 3.6; WGII 20.2, 20.9, SPM; WGIII 3.5, 3.6, SPM}*

5.2 Key vulnerabilities, impacts and risks – long-term perspectives

The five 'reasons for concern' identified in the TAR are now assessed to be stronger with many risks identified with higher confidence. Some are projected to be larger or to occur at lower increases in temperature. This is due to (1) better understanding of the magnitude of impacts and risks associated with increases in global average temperature and GHG concentrations, including vulnerability to present-day climate variability, (2) more precise identification of the circumstances that make systems, sectors, groups and regions especially vulnerable and (3) growing evidence that the risk of very large impacts on multiple century time scales would continue to increase as long as GHG concentrations and temperature continue to increase. Understanding about the relationship between impacts (the basis for 'reasons for concern' in the TAR) and vulnerability (that includes the ability to adapt to impacts) has improved. *{WGII 4.4, 5.4, 19.ES, 19.3.7, TS.4.6; WGIII 3.5, SPM}*

The TAR concluded that vulnerability to climate change is a function of exposure, sensitivity and adaptive capacity. Adaptation can reduce sensitivity to climate change while mitigation can reduce the exposure to climate change, including its rate and extent. Both conclusions are confirmed in this assessment. *{WGII 20.2, 20.7.3}*

No single metric can adequately describe the diversity of key vulnerabilities or support their ranking. A sample of relevant impacts is provided in Figure 3.6. The estimation of key vulnerabilities in any system, and damage implied, will depend on exposure (the rate and magnitude of climate change), sensitivity, which is determined in part and where relevant by development status, and adaptive capacity. Some key vulnerabilities may be linked to thresholds; in some cases these may cause a system to shift from one state to another, whereas others have thresholds that are defined subjectively and thus depend on societal values. *{WGII 19.ES, 19.1}*

The five 'reasons for concern' that were identified in the TAR were intended to synthesise information on climate risks and key vulnerabilities and to "aid readers in making their own determination" about risk. These remain a viable framework to consider key vulnerabilities, and they have been updated in the AR4. *{TAR WGII Chapter 19; WGII SPM}*

- ***Risks to unique and threatened systems.*** There is new and stronger evidence of observed impacts of climate change on unique and vulnerable systems (such as polar and high mountain communities and ecosystems), with increasing levels of adverse impacts as temperatures increase further. An increasing risk of species extinction and coral reef damage is projected with higher confidence than in the TAR as warming proceeds. There is *medium confidence* that approximately 20 to 30% of plant and animal species assessed so far are *likely* to be at increased risk of extinction if increases in global average temperature exceed 1.5 to 2.5°C over 1980-1999 levels. Confidence has increased that a 1 to 2°C increase in global mean temperature above 1990 levels (about 1.5 to 2.5°C above pre-indus-

Key Vulnerabilities and Article 2 of the UNFCCC

Article 2 of the UNFCCC states:

"The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner."

Determining what constitutes "dangerous anthropogenic interference with the climate system" in relation to Article 2 of the UNFCCC involves value judgements. Science can support informed decisions on this issue, including by providing criteria for judging which vulnerabilities might be labelled 'key'. *{SYR 3.3, WGII 19.ES}*

Key vulnerabilities[25] may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation. *{WGII 19.ES}*

More specific information is now available across the regions of the world concerning the nature of future impacts, including for some places not covered in previous assessments. *{WGII SPM}*

[25] Key Vulnerabilities can be identified based on a number of criteria in the literature, including magnitude, timing, persistence/reversibility, the potential for adaptation, distributional aspects, likelihood and 'importance' of the impacts.

trial) poses significant risks to many unique and threatened systems including many biodiversity hotspots. Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatisation by corals. Increasing vulnerability of Arctic indigenous communities and small island communities to warming is projected. *{SYR 3.3, 3.4, Figure 3.6, Table 3.2; WGII 4.ES, 4.4, 6.4, 14.4.6, 15.ES, 15.4, 15.6, 16.ES, 16.2.1, 16.4, Table 19.1, 19.3.7, TS.5.3, Figure TS.12, Figure TS.14}*

- ***Risks of extreme weather events.*** Responses to some recent extreme climate events reveal higher levels of vulnerability in both developing and developed countries than was assessed in the TAR. There is now higher confidence in the projected increases in droughts, heat waves and floods, as well as their adverse impacts. As summarised in Table 3.2, increases in drought, heat waves and floods are projected in many regions and would have mostly adverse impacts, including increased water stress and wild fire frequency, adverse effects on food production, adverse health effects, increased flood risk and extreme high sea level, and damage to infrastructure. *{SYR 3.2, 3.3, Table 3.2; WGI 10.3, Table SPM.2; WGII 1.3, 5.4, 7.1, 7.5, 8.2, 12.6, 19.3, Table 19.1, Table SPM.1}*
- ***Distribution of impacts and vulnerabilities.*** There are sharp differences across regions and those in the weakest economic position are often the most vulnerable to climate change and are frequently the most susceptible to climate-related damages, especially when they face multiple stresses. There is increasing evidence of greater vulnerability of specific groups such as the poor and elderly not only in developing but also in developed countries. There is greater confidence in the projected regional patterns of climate change (see Topic 3.2) and in the projections of regional impacts, enabling better identification of particularly vulnerable systems, sectors and regions (see Topic 3.3). Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and megadeltas. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small island communities. *{SYR 3.2, 3.3, 5.4; WGI 11.2-11.7, SPM; WGII 3.4.3, 5.3, 5.4, Boxes 7.1 and 7.4, 8.1.1, 8.4.2, 8.6.1.3, 8.7, 9.ES, Table 10.9, 10.6, 16.3, 19.ES, 19.3, Table 19.1, 20.ES, TS.4.5, TS.5.4, Tables TS.1, TS.3, TS.4, SPM}*
- ***Aggregate impacts.*** Compared to the TAR, initial net market-based benefits from climate change are projected to peak at a lower magnitude and therefore sooner than was assessed in the TAR. It is *likely* that there will be higher damages for larger magnitudes of global temperature increase than estimated in the TAR, and the net costs of impacts of increased warming are projected to increase over time. Aggregate impacts have also been quantified in other metrics (see Topic 3.3): for example, climate change over the next century is *likely* to adversely affect hundreds of millions of people through increased coastal flooding, reductions in water supplies, increased malnutrition and increased health impacts. *{SYR 3.3, Figure 3.6; WGII 19.3.7, 20.7.3, TS.5.3}*
- ***Risks of large-scale singularities.***[26] As discussed in Topic 3.4, during the current century, a large-scale abrupt change in the meridional overturning circulation is *very unlikely*. There is *high confidence* that global warming over many centuries would lead to a sea level rise contribution from thermal expansion alone that is projected to be much larger than observed over the 20th century, with loss of coastal area and associated impacts. There is better understanding than in the TAR that the risk of additional contributions to sea level rise from both the Greenland and possibly Antarctic ice sheets may be larger than projected by ice sheet models and could occur on century time scales. This is because ice dynamical processes seen in recent observations but not fully included in ice sheet models assessed in the AR4 could increase the rate of ice loss. Complete deglaciation of the Greenland ice sheet would raise sea level by 7m and could be irreversible. *{SYR 3.4; WGI 10.3, Box 10.1; WGII 19.3.7, SPM}*

5.3 Adaptation and mitigation

There is *high confidence* that neither adaptation nor mitigation alone can avoid all climate change impacts. Adaptation is necessary both in the short term and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed. There are barriers, limits and costs that are not fully understood. Adaptation and mitigation can complement each other and together can significantly reduce the risks of climate change. ***{WGII 4.ES, TS 5.1, 18.4, 18.6, 20.7, SPM; WGIII 1.2, 2.5, 3.5, 3.6}***

Adaptation will be ineffective for some cases such as natural ecosystems (e.g. loss of Arctic sea ice and marine ecosystem viability), the disappearance of mountain glaciers that play vital roles in water storage and supply, or adaptation to sea level rise of several metres[27]. It will be less feasible or very costly in many cases for the projected climate change beyond the next several decades (such as deltaic regions and estuaries). There is *high confidence* that the ability of many ecosystems to adapt naturally will be exceeded this century. In addition, multiple barriers and constraints to effective adaptation exist in human systems (see Topic 4.2). *{SYR 4.2; WGII 17.4.2, 19.2, 19.4.1}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. Reliance on adaptation alone could eventually lead to a magnitude of climate change to which effective adaptation is not possible, or will only be available at very high social, environmental and economic costs. *{WGII 18.1, SPM}*

[26] See glossary

[27] While it is technically possible to adapt to several metres of sea level rise, the resources required are so unevenly distributed that in reality this risk is outside the scope of adaptation. {WGII 17.4.2, 19.4.1}

Efforts to mitigate GHG emissions to reduce the rate and magnitude of climate change need to account for inertia in the climate and socio-economic systems. *{SYR 3.2; WGI 10.3, 10.4, 10.7, SPM; WGIII 2.3.4}*

After GHG concentrations are stabilised, the rate at which the global average temperature increases is expected to slow within a few decades. Small increases in global average temperature could still be expected for several centuries. Sea level rise from thermal expansion would continue for many centuries at a rate that eventually decreases from that reached before stabilisation, due to ongoing heat uptake by oceans. *{SYR 3.2, WGI 10.3, 10.4, 10.7, SPM}*

Delayed emission reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. Even though benefits of mitigation measures in terms of avoided climate change would take several decades to materialise, mitigation actions begun in the short term would avoid locking in both long-lived carbon intensive infrastructure and development pathways, reduce the rate of climate change and reduce the adaptation needs associated with higher levels of warming. *{WGII 18.4, 20.6, 20.7, SPM; WGIII 2.3.4, 3.4, 3.5, 3.6, SPM}*

5.4 Emission trajectories for stabilisation

In order to stabilise the concentration of GHGs in the atmosphere, emissions would need to peak and decline thereafter.[28] The lower the stabilisation level, the more quickly this peak and decline would need to occur (Figure 5.1).[29] *{WGIII 3.3, 3.5, SPM}*

Advances in modelling since the TAR permit the assessment of multi-gas mitigation strategies for exploring the attainability and costs for achieving stabilisation of GHG concentrations. These scenarios explore a wider range of future scenarios, including lower levels of stabilisation, than reported in the TAR. *{WGIII 3.3, 3.5, SPM}*

Mitigation efforts over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels (Table 5.1 and Figure 5.1). *{WGIII 3.5, SPM}*

Table 5.1 summarises the required emission levels for different groups of stabilisation concentrations and the resulting equilibrium

CO_2 emissions and equilibrium temperature increases for a range of stabilisation levels

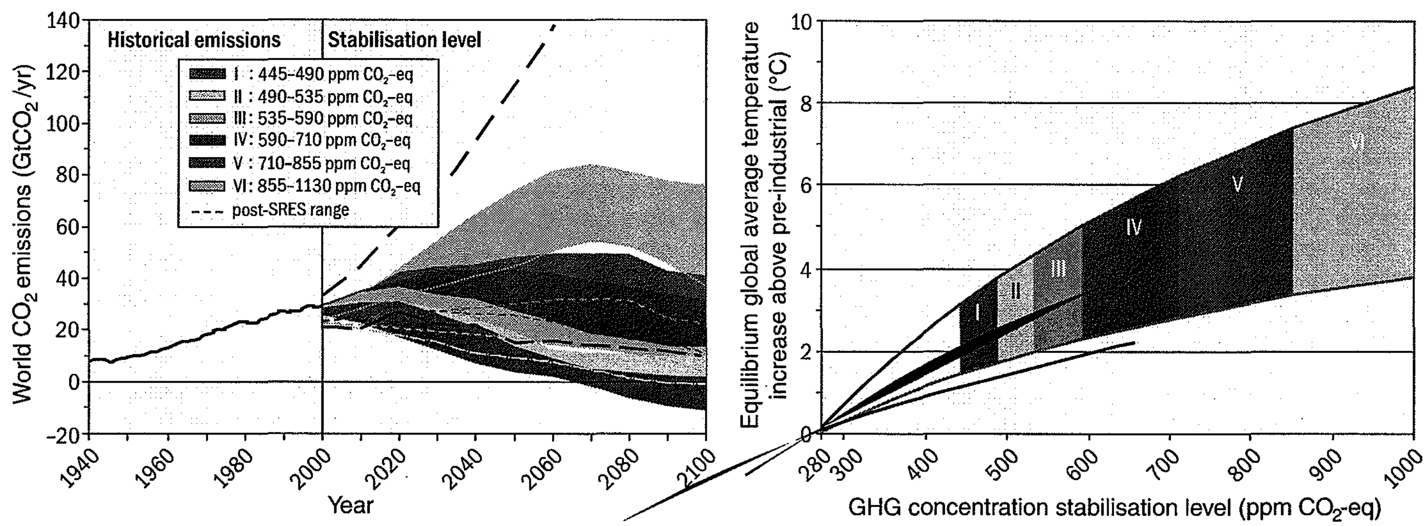


Figure 5.1. Global CO_2 emissions for 1940 to 2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100 (left-hand panel); and the corresponding relationship between the stabilisation target and the likely *equilibrium global average temperature increase above pre-industrial (right-hand panel). Approaching equilibrium can take several centuries, especially for scenarios with higher levels of stabilisation. Coloured shadings show stabilisation scenarios grouped according to different targets (stabilisation category I to VI). The right-hand panel shows ranges of global average temperature change above pre-industrial, using (i) 'best estimate' climate sensitivity of 3°C (black line in middle of shaded area), (ii) upper bound of* likely *range of climate sensitivity of 4.5°C (red line at top of shaded area) (iii) lower bound of* likely *range of climate sensitivity of 2°C (blue line at bottom of shaded area). Black dashed lines in the left panel give the emissions range of recent baseline scenarios published since the SRES (2000). Emissions ranges of the stabilisation scenarios comprise CO_2-only and multigas scenarios and correspond to the 10^{th} to 90^{th} percentile of the full scenario distribution. Note: CO_2 emissions in most models do not include emissions from decay of above ground biomass that remains after logging and deforestation, and from peat fires and drained peat soils. {WGIII Figures SPM.7 and SPM.8}*

[28] Peaking means that the emissions need to reach a maximum before they decline later.

[29] For the lowest mitigation scenario category assessed, emissions would need to peak by 2015 and for the highest by 2090 (see Table 5.1). Scenarios that use alternative emission pathways show substantial differences on the rate of global climate change. {WGII 19.4}

***Table 5.1.** Characteristics of post-TAR stabilisation scenarios and resulting long-term equilibrium global average temperature and the sea level rise component from thermal expansion only.[a] {WGI 10.7; WGIII Table TS.2, Table 3.10, Table SPM.5}*

Category	CO_2 concentration at stabilisation (2005 = 379 ppm)[b]	CO_2-equivalent concentration at stabilisation including GHGs and aerosols (2005=375 ppm)[b]	Peaking year for CO_2 emissions[a,c]	Change in global CO_2 emissions in 2050 (percent of 2000 emissions)[a,c]	Global average temperature increase above pre-industrial at equilibrium, using 'best estimate' climate sensitivity[d,e]	Global average sea level rise above pre-industrial at equilibrium from thermal expansion only[f]	Number of assessed scenarios
	ppm	ppm	year	percent	°C	metres	
I	350 – 400	445 – 490	2000 – 2015	-85 to -50	2.0 – 2.4	0.4 – 1.4	6
II	400 – 440	490 – 535	2000 – 2020	-60 to -30	2.4 – 2.8	0.5 – 1.7	18
III	440 – 485	535 – 590	2010 – 2030	-30 to +5	2.8 – 3.2	0.6 – 1.9	21
IV	485 – 570	590 – 710	2020 – 2060	+10 to +60	3.2 – 4.0	0.6 – 2.4	118
V	570 – 660	710 – 855	2050 – 2080	+25 to +85	4.0 – 4.9	0.8 – 2.9	9
VI	660 – 790	855 – 1130	2060 – 2090	+90 to +140	4.9 – 6.1	1.0 – 3.7	5

Notes:

a) The emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed here might be underestimated due to missing carbon cycle feedbacks (see also Topic 2.3).

b) Atmospheric CO_2 concentrations were 379ppm in 2005. The best estimate of total CO_2-eq concentration in 2005 for all long-lived GHGs is about 455ppm, while the corresponding value including the net effect of all anthropogenic forcing agents is 375ppm CO_2-eq.

c) Ranges correspond to the 15[th] to 85[th] percentile of the post-TAR scenario distribution. CO_2 emissions are shown so multi-gas scenarios can be compared with CO_2-only scenarios (see Figure 2.1).

d) The best estimate of climate sensitivity is 3°C.

e) Note that global average temperature at equilibrium is different from expected global average temperature at the time of stabilisation of GHG concentrations due to the inertia of the climate system. For the majority of scenarios assessed, stabilisation of GHG concentrations occurs between 2100 and 2150 (see also Footnote 30).

f) Equilibrium sea level rise is for the contribution from ocean thermal expansion only and does not reach equilibrium for at least many centuries. These values have been estimated using relatively simple climate models (one low-resolution AOGCM and several EMICs based on the best estimate of 3°C climate sensitivity) and do not include contributions from melting ice sheets, glaciers and ice caps. Long-term thermal expansion is projected to result in 0.2 to 0.6m per degree Celsius of global average warming above pre-industrial. (AOGCM refers to Atmosphere-Ocean General Circulation Model and EMICs to Earth System Models of Intermediate Complexity.)

global average temperature increases, using the 'best estimate' of climate sensitivity (see Figure 5.1 for the *likely* range of uncertainty). Stabilisation at lower concentration and related equilibrium temperature levels advances the date when emissions need to peak and requires greater emissions reductions by 2050.[30] Climate sensitivity is a key uncertainty for mitigation scenarios that aim to meet specific temperature levels. The timing and level of mitigation to reach a given temperature stabilisation level is earlier and more stringent if climate sensitivity is high than if it is low. *{WGIII 3.3, 3.4, 3.5, 3.6, SPM}*

Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21[st] century (Table 5.1). If GHG and aerosol concentrations had been stabilised at year 2000 levels, thermal expansion alone would be expected to lead to further sea level rise of 0.3 to 0.8m. The eventual contributions from Greenland ice sheet loss could be several metres, and larger than from thermal expansion, should warming in excess of 1.9 to 4.6°C above pre-industrial be sustained over many centuries. These long-term consequences would have major implications for world coastlines. The long time scale of thermal expansion and ice sheet response to warming imply that mitigation strategies that seek to stabilise GHG concentrations (or radiative forcing) at or above present levels do not stabilise sea level for many centuries. *{WGI 10.7}*

Feedbacks between the carbon cycle and climate change affect the required mitigation and adaptation response to climate change. Climate-carbon cycle coupling is expected to increase the fraction of anthropogenic emissions that remains in the atmosphere as the climate system warms (see Topics 2.3 and 3.2.1), but mitigation studies have not yet incorporated the full range of these feedbacks. As a consequence, the emission reductions to meet a particular stabilisation level reported in the mitigation studies assessed in Table 5.1 might be underestimated. Based on current understanding of climate-carbon cycle feedbacks, model studies suggest that stabilising CO_2 concentrations at, for example, 450ppm[31] could require cumulative emissions over the 21[st] century to be less than 1800 [1370 to 2200] $GtCO_2$, which is about 27% less than the 2460 [2310 to 2600] $GtCO_2$ determined without consideration of carbon cycle feedbacks. *{SYR 2.3, 3.2.1; WGI 7.3, 10.4, SPM}*

[30] Estimates for the evolution of temperature over the course of this century are not available in the AR4 for the stabilisation scenarios. For most stabilisation levels global average temperature is approaching the equilibrium level over a few centuries. For the much lower stabilisation scenarios (category I and II, Figure 5.1), the equilibrium temperature may be reached earlier.

[31] To stabilise at 1000ppm CO_2, this feedback could require that cumulative emissions be reduced from a model average of approximately 5190 [4910 to 5460] $GtCO_2$ to approximately 4030 [3590 to 4580] $GtCO_2$. {WGI 7.3, 10.4, SPM}

5.5 Technology flows and development

There is *high agreement* and *much evidence* that all stabilisation levels assessed can be achieved by deployment of a portfolio of technologies that are either currently available or expected to be commercialised in coming decades, assuming appropriate and effective incentives are in place for development, acquisition, deployment and diffusion of technologies and addressing related barriers. ***{WGIII SPM}***

Worldwide deployment of low-GHG emission technologies as well as technology improvements through public and private RD&D would be required for achieving stabilisation targets as well as cost reduction.[32] Figure 5.2 gives illustrative examples of the contribution of the portfolio of mitigation options. The contribution of different technologies varies over time and region and depends on the baseline development path, available technologies and relative costs, and the analysed stabilisation levels. Stabilisation at the lower of the assessed levels (490 to 540ppm CO_2-eq) requires early investments and substantially more rapid diffusion and commercialisation of advanced low-emissions technologies over the next decades (2000-2030) and higher contributions across abatement options in the long term (2000-2100). This requires that barriers to development, acquisition, deployment and diffusion of technologies are effectively addressed with appropriate incentives. *{WGIII 2.7, 3.3, 3.4, 3.6, 4.3, 4.4, 4.6, SPM}*

Without sustained investment flows and effective technology transfer, it may be difficult to achieve emission reduction at a significant scale. Mobilising financing of incremental costs of low-carbon technologies is important. *{WGIII 13.3, SPM}*

There are large uncertainties concerning the future contribution of different technologies. However, all assessed stabilisation scenarios concur that 60 to 80% of the reductions over the course of the century would come from energy supply and use and industrial processes. Including non-CO_2 and CO_2 land-use and forestry mitigation options provides greater flexibility and cost-effectiveness. Energy efficiency plays a key role across many scenarios for most regions and time scales. For lower stabilisation levels, scenarios put more emphasis on the use of low-carbon energy sources, such as renewable energy, nuclear power and the use of CO_2 capture and storage (CCS). In these scenarios, improvements of carbon intensity of energy supply and the whole economy needs to be much faster than in the past (Figure 5.2). *{WGIII 3.3, 3.4, TS.3, SPM}*

Illustrative mitigation portfolios for achieving stabilisation of GHG concentrations

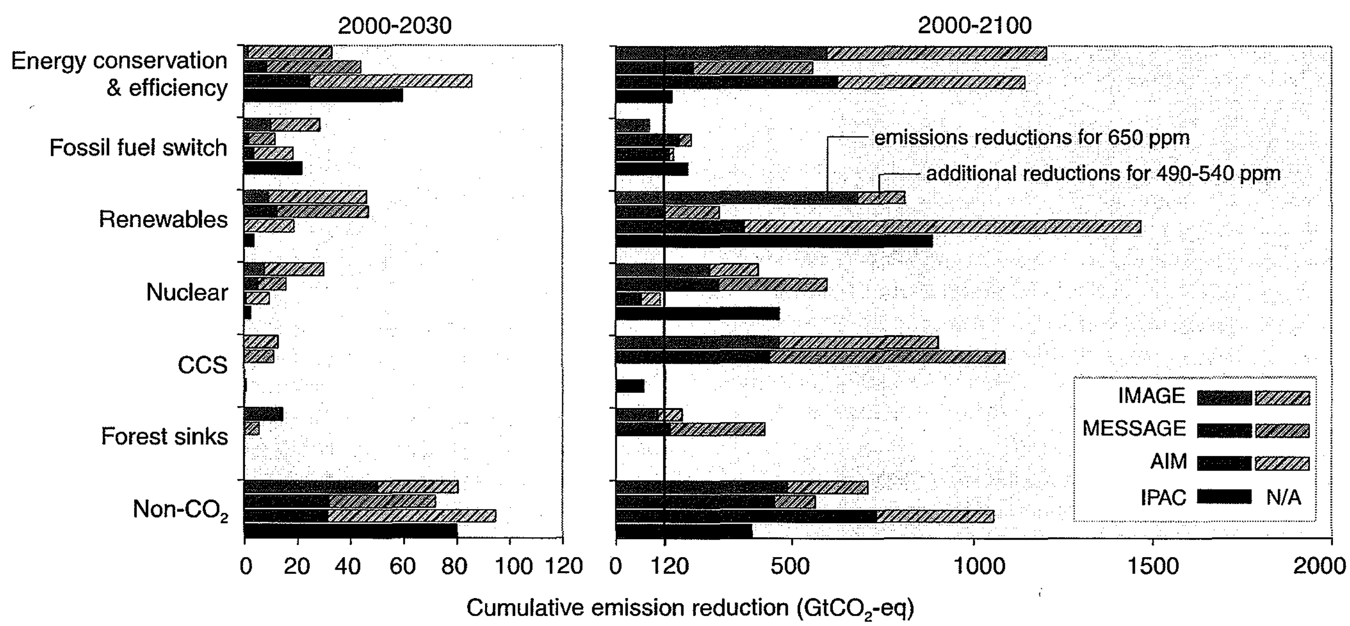


Figure 5.2 *Cumulative emissions reductions for alternative mitigation measures for 2000-2030 (left-hand panel) and for 2000-2100 (right-hand panel). The figure shows illustrative scenarios from four models (AIM, IMAGE, IPAC and MESSAGE) aiming at the stabilisation at low (490 to 540ppm CO_2-eq) and intermediate levels (650ppm CO_2-eq) respectively. Dark bars denote reductions for a target of 650ppm CO_2-eq and light bars denote the additional reductions to achieve 490 to 540ppm CO_2-eq. Note that some models do not consider mitigation through forest sink enhancement (AIM and IPAC) or CCS (AIM) and that the share of low-carbon energy options in total energy supply is also determined by inclusion of these options in the baseline. CCS includes CO_2 capture and storage from biomass. Forest sinks include reducing emissions from deforestation. The figure shows emissions reductions from baseline scenarios with cumulative emissions between 6000 to 7000 $GtCO_2$-eq (2000-2100). {WGIII Figure SPM.9}*

[32] By comparison, government funding in real absolute terms for most energy research programmes has been flat or declining for nearly two decades (even after the UNFCCC came into force) and is now about half of the 1980 level. {WGIII 2.7, 3.4, 4.5, 11.5, 13.2}

5.6 Costs of mitigation and long-term stabilisation targets

The macro-economic costs of mitigation generally rise with the stringency of the stabilisation target and are relatively higher when derived from baseline scenarios characterised by high emission levels. *{WGIII SPM}*

There is *high agreement* and *medium evidence* that in 2050 global average macro-economic costs for multi-gas mitigation towards stabilisation between 710 and 445ppm CO_2-eq are between a 1% gain to a 5.5% decrease of global GDP (Table 5.2). This corresponds to slowing average annual global GDP growth by less than 0.12 percentage points. Estimated GDP losses by 2030 are on average lower and show a smaller spread compared to 2050 (Table 5.2). For specific countries and sectors, costs vary considerably from the global average.[33] *{WGIII 3.3, 13.3, SPM}*

5.7 Costs, benefits and avoided climate impacts at global and regional levels

Impacts of climate change will vary regionally. Aggregated and discounted to the present, they are *very likely* to impose net annual costs, which will increase over time as global temperatures increase. *{WGII SPM}*

For increases in global average temperature of less than 1 to 3°C above 1980-1999 levels, some impacts are projected to produce market benefits in some places and sectors while, at the same time, imposing costs in other places and sectors. Global mean losses could be 1 to 5% of GDP for 4°C of warming, but regional losses could be substantially higher. *{WGII 9.ES, 10.6, 15.ES, 20.6, SPM}*

Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change aggregated across the globe and discounted to the present) for 2005 have an average value of US$12 per tonne of CO_2, but the range from 100 estimates is large (-$3 to $95/t$CO_2$). The range of published evidence indicates that the net damage costs of climate change are projected to be significant and to increase over time. *{WGII 20.6, SPM}*

It is *very likely* that globally aggregated figures underestimate the damage costs because they cannot include many non-quantifiable impacts. It is *virtually certain* that aggregate estimates of costs mask significant differences in impacts across sectors, regions, countries and populations. In some locations and amongst some groups of people with high exposure, high sensitivity and/or low adaptive capacity, net costs will be significantly larger than the global average. *{WGII 7.4, 20.ES, 20.6, 20.ES, SPM}*

Limited and early analytical results from integrated analyses of the global costs and benefits of mitigation indicate that these are broadly comparable in magnitude, but do not as yet permit an unambiguous determination of an emissions pathway or stabilisation level where benefits exceed costs. *{WGIII SPM}*

Comparing the costs of mitigation with avoided damages would require the reconciliation of welfare impacts on people living in different places and at different points in time into a global aggregate measure of well-being. *{WGII 18.ES}*

Choices about the scale and timing of GHG mitigation involve balancing the economic costs of more rapid emission reductions now against the corresponding medium-term and long-term climate risks of delay. *{WGIII SPM}*

Many impacts can be avoided, reduced or delayed by mitigation. *{WGII SPM}*

Although the small number of impact assessments that evaluate stabilisation scenarios do not take full account of uncertainties in projected climate under stabilisation, they nevertheless provide indications of damages avoided and risks reduced for different

Table 5.2. *Estimated global macro-economic costs in 2030 and 2050. Costs are relative to the baseline for least-cost trajectories towards different long-term stabilisation levels. {WGIII 3.3, 13.3, Tables SPM.4 and SPM.6}*

Stabilisation levels (ppm CO_2-eq)	Median GDP reduction[a] (%)		Range of GDP reduction[b] (%)		Reduction of average annual GDP growth rates (percentage points)[c,e]	
	2030	2050	2030	2050	2030	2050
445 – 535[d]	Not available		<3	<5.5	< 0.12	< 0.12
535 – 590	0.6	1.3	0.2 to 2.5	slightly negative to 4	< 0.1	< 0.1
590 – 710	0.2	0.5	-0.6 to 1.2	-1 to 2	< 0.06	< 0.05

Notes:
Values given in this table correspond to the full literature across all baselines and mitigation scenarios that provide GDP numbers.
a) Global GDP based on market exchange rates.
b) The 10th and 90th percentile range of the analysed data are given where applicable. Negative values indicate GDP gain. The first row (445-535ppm CO_2-eq) gives the upper bound estimate of the literature only.
c) The calculation of the reduction of the annual growth rate is based on the average reduction during the assessed period that would result in the indicated GDP decrease by 2030 and 2050 respectively.
d) The number of studies is relatively small and they generally use low baselines. High emissions baselines generally lead to higher costs.
e) The values correspond to the highest estimate for GDP reduction shown in column three.

[33] See Footnote 24 for further details on cost estimates and model assumptions.

amounts of emissions reduction. The rate and magnitude of future human-induced climate change and its associated impacts are determined by human choices defining alternative socio-economic futures and mitigation actions that influence emission pathways. Figure 3.2 demonstrates that alternative SRES emission pathways could lead to substantial differences in climate change throughout the 21st century. Some of the impacts at the high temperature end of Figure 3.6 could be avoided by socio-economic development pathways that limit emissions and associated climate change towards the lower end of the ranges illustrated in Figure 3.6. *{SYR 3.2, 3.3; WGIII 3.5, 3.6, SPM}*

Figure 3.6 illustrates how reduced warming could reduce the risk of, for example, affecting a significant number of ecosystems, the risk of extinctions, and the likelihood that cereal productivity in some regions would tend to fall. *{SYR 3.3, Figure 3.6; WGII 4.4, 5.4, Table 20.6}*

5.8 Broader environmental and sustainability issues

Sustainable development can reduce vulnerability to climate change, and climate change could impede nations' abilities to achieve sustainable development pathways. ***{WGII SPM}***

It is *very likely* that climate change can slow the pace of progress toward sustainable development either directly through increased exposure to adverse impacts or indirectly through erosion of the capacity to adapt. Over the next half-century, climate change could impede achievement of the Millennium Development Goals. *{WGII SPM}*

Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Their combined impacts may be compounded in future in the absence of integrated mitigation and adaptation measures. *{WGII 20.3, 20.7, 20.8, SPM}*

Making development more sustainable can enhance mitigative and adaptive capacities, reduce emissions, and reduce vulnerability, but there may be barriers to implementation. ***{WGII 20.8; WGIII 12.2, SPM}***

Both adaptive and mitigative capacities can be enhanced through sustainable development. Sustainable development can, thereby, reduce vulnerability to climate change by reducing sensitivities (through adaptation) and/or exposure (through mitigation). At present, however, few plans for promoting sustainability have explicitly included either adapting to climate change impacts, or promoting adaptive capacity. Similarly, changing development paths can make a major contribution to mitigation but may require resources to overcome multiple barriers. *{WGII 20.3, 20.5, SPM; WGIII 2.1, 2.5, 12.1, SPM}*

6

Robust findings, key uncertainties

Robust findings, key uncertainties

As in the TAR, a robust finding for climate change is defined as one that holds under a variety of approaches, methods, models and assumptions, and is expected to be relatively unaffected by uncertainties. Key uncertainties are those that, if reduced, could lead to new robust findings. *{TAR SYR Q.9}*

Robust findings do not encompass all key findings of the AR4. Some key findings may be policy-relevant even though they are associated with large uncertainties. *{WGII 20.9}*

The robust findings and key uncertainties listed below do not represent an exhaustive list.

6.1 Observed changes in climate and their effects, and their causes

Robust findings

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. *{WGI 3.9, SPM}*

Many natural systems, on all continents and in some oceans, are being affected by regional climate changes. Observed changes in many physical and biological systems are consistent with warming. As a result of the uptake of anthropogenic CO_2 since 1750, the acidity of the surface ocean has increased. *{WGI 5.4, WGII 1.3}*

Global total annual anthropogenic GHG emissions, weighted by their 100-year GWPs, have grown by 70% between 1970 and 2004. As a result of anthropogenic emissions, atmospheric concentrations of N_2O now far exceed pre-industrial values spanning many thousands of years, and those of CH_4 and CO_2 now far exceed the natural range over the last 650,000 years. *{WGI SPM; WGIII 1.3}*

Most of the global average warming over the past 50 years is *very likely* due to anthropogenic GHG increases and it is *likely* that there is a discernible human-induced warming averaged over each continent (except Antarctica). *{WGI 9.4, SPM}*

Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems. *{WGII 1.4, SPM}*

Key uncertainties

Climate data coverage remains limited in some regions and there is a notable lack of geographic balance in data and literature on observed changes in natural and managed systems, with marked scarcity in developing countries. *{WGI SPM; WGII 1.3, SPM}*

Analysing and monitoring changes in extreme events, including drought, tropical cyclones, extreme temperatures and the frequency and intensity of precipitation, is more difficult than for climatic averages as longer data time-series of higher spatial and temporal resolutions are required. *{WGI 3.8, SPM}*

Effects of climate changes on human and some natural systems are difficult to detect due to adaptation and non-climatic drivers. *{WGII 1.3}*

Difficulties remain in reliably simulating and attributing observed temperature changes to natural or human causes at smaller than continental scales. At these smaller scales, factors such as land-use change and pollution also complicate the detection of anthropogenic warming influence on physical and biological systems. *{WGI 8.3, 9.4, SPM; WGII 1.4, SPM}*

The magnitude of CO_2 emissions from land-use change and CH_4 emissions from individual sources remain as key uncertainties. *{WGI 2.3, 7.3, 7.4; WGIII 1.3, TS.14}*

6.2 Drivers and projections of future climate changes and their impacts

Robust findings

With current climate change mitigation policies and related sustainable development practices, global GHG emissions will continue to grow over the next few decades. *{WGIII 3.2, SPM}*

For the next two decades a warming of about 0.2°C per decade is projected for a range of SRES emissions scenarios. *{WGI 10.3, 10.7, SPM}*

Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century. *{WGI 10.3, 11.1, SPM}*

The pattern of future warming where land warms more than the adjacent oceans and more in northern high latitudes is seen in all scenarios. *{WGI 10.3, 11.1, SPM}*

Warming tends to reduce terrestrial ecosystem and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions that remains in the atmosphere. *{WGI 7.3, 10.4, 10.5, SPM}*

Anthropogenic warming and sea level rise would continue for centuries even if GHG emissions were to be reduced sufficiently for GHG concentrations to stabilise, due to the time scales associated with climate processes and feedbacks. *{WGI 10.7, SPM}*

Equilibrium climate sensitivity is *very unlikely* to be less than 1.5°C. *{WGI 8.6, 9.6, Box 10.2, SPM}*

Some systems, sectors and regions are *likely* to be especially affected by climate change. The systems and sectors are some ecosystems (tundra, boreal forest, mountain, mediterranean-type, mangroves, salt marshes, coral reefs and the sea-ice biome), low-lying coasts, water resources in some dry regions at mid-latitudes and in the dry topics and in areas dependent on snow and ice melt, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. The regions are the Arctic, Africa, small islands and Asian and African megadeltas. Within other regions, even those with high incomes, some people, areas and activities can be particularly at risk. *{WGII TS.4.5}*

Impacts are *very likely* to increase due to increased frequencies and intensities of some extreme weather events. Recent events have demonstrated the vulnerability of some sectors and regions, including in developed countries, to heat waves, tropical cyclones, floods and drought, providing stronger reasons for concern as compared to the findings of the TAR. *{WGII Table SPM.2, 19.3}*

Key uncertainties

Uncertainty in the equilibrium climate sensitivity creates uncertainty in the expected warming for a given CO_2-eq stabilisation scenario. Uncertainty in the carbon cycle feedback creates uncertainty in the emissions trajectory required to achieve a particular stabilisation level. *{WGI 7.3, 10.4, 10.5, SPM}*

Models differ considerably in their estimates of the strength of different feedbacks in the climate system, particularly cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks, although progress has been made in these areas. Also, the confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer time averaging periods. *{WGI 7.3, 8.1-8.7, 9.6, 10.2, 10.7, SPM; WGII 4.4}*

Aerosol impacts on the magnitude of the temperature response, on clouds and on precipitation remain uncertain. *{WGI 2.9, 7.5, 9.2, 9.4, 9.5}*

Future changes in the Greenland and Antarctic ice sheet mass, particularly due to changes in ice flow, are a major source of uncertainty that could increase sea level rise projections. The uncertainty in the penetration of the heat into the oceans also contributes to the future sea level rise uncertainty. *{WGI 4.6, 6.4, 10.3, 10.7, SPM}*

Large-scale ocean circulation changes beyond the 21st century cannot be reliably assessed because of uncertainties in the meltwater supply from the Greenland ice sheet and model response to the warming. *{WGI 6.4, 8.7, 10.3 }*

Projections of climate change and its impacts beyond about 2050 are strongly scenario- and model-dependent, and improved projections would require improved understanding of sources of uncertainty and enhancements in systematic observation networks. *{WGII TS.6}*

Impacts research is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. *{WGII TS.6}*

Understanding of low-probability/high-impact events and the cumulative impacts of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited. *{WGII 19.4, 20.2, 20.4, 20.9, TS.6}*

6.3 Responses to climate change

Robust findings

Some planned adaptation (of human activities) is occurring now; more extensive adaptation is required to reduce vulnerability to climate change. *{WGII 17.ES, 20.5, Table 20.6, SPM}*

Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt. *{WGII 20.7, SPM}*

A wide range of mitigation options is currently available or projected to be available by 2030 in all sectors. The economic mitigation potential, at costs that range from net negative up to US$100/$tCO_2$-equivalent, is sufficient to offset the projected growth of global emissions or to reduce emissions to below current levels in 2030. *{WGIII 11.3, SPM}*

Many impacts can be reduced, delayed or avoided by mitigation. Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels. Delayed emissions reductions significantly constrain the opportunities to achieve lower stabilisation levels and increase the risk of more severe climate change impacts. *{WGII SPM, WGIII SPM}*

The range of stabilisation levels for GHG concentrations that have been assessed can be achieved by deployment of a portfolio of technologies that are currently available and those that are expected to be commercialised in coming decades, provided that appropriate and effective incentives are in place and barriers are removed. In addition, further RD&D would be required to improve the technical performance, reduce the costs and achieve social acceptability of new technologies. The lower the stabilisation levels, the greater the need for investment in new technologies during the next few decades. *{WGIII 3.3, 3.4}*

Making development more sustainable by changing development paths can make a major contribution to climate change mitigation and adaptation and to reducing vulnerability. *{WGII 18.7, 20.3, SPM; WGIII 13.2, SPM}*

Decisions about macro-economic and other policies that seem unrelated to climate change can significantly affect emissions. *{WGIII 12.2}*

Key uncertainties

Understanding of how development planners incorporate information about climate variability and change into their decisions is limited. This limits the integrated assessment of vulnerability. *{WGII 18.8, 20.9}*

The evolution and utilisation of adaptive and mitigative capacity depend on underlying socio-economic development pathways. *{WGII 17.3, 17.4, 18.6, 19.4, 20.9}*

Barriers, limits and costs of adaptation are not fully understood, partly because effective adaptation measures are highly dependent on specific geographical and climate risk factors as well as institutional, political and financial constraints. *{WGII SPM}*

Estimates of mitigation costs and potentials depend on assumptions about future socio-economic growth, technological change and consumption patterns. Uncertainty arises in particular from assumptions regarding the drivers of technology diffusion and the potential of long-term technology performance and cost improvements. Also little is known about the effects of changes in behaviour and lifestyles. *{WGIII 3.3, 3.4, 11.3}*

The effects of non-climate policies on emissions are poorly quantified. *{WGIII 12.2}*

Exhibit 3

Approved baseline and monitoring methodology AM0025

"Avoided emissions from organic waste through alternative waste treatment processes"

I. SOURCE AND APPLICABILITY

Source

This baseline methodology is based on the following proposed methodologies:

- NM0090: "Organic waste composting at the Matuail landfill site Dhaka, Bangladesh" whose baseline study, monitoring and verification plan and project design document were prepared by World Wide Recycling B.V. and Waste Concern;
- NM0127: "PT Navigat Organic Energy Indonesia Integrated Solid Waste Management (GALFAD) project in Bali, Indonesia" whose baseline study, monitoring and verification plan and project design document were prepared by Mitsubishi Securities Co.;
- NM0032: "Municipal solid waste treatment cum energy generation project, Lucknow, India" whose baseline study, monitoring and verification plan were prepared by Infrastructure Development Finance Company Limited on behalf of Prototype Carbon Fund;
- NM0178: "Aerobic thermal treatment of municipal solid waste (MSW) without incineration in Parobé - RS" whose baseline study, monitoring and verification plan and project design document were prepared by ICF Consulting;
- NM0174-rev: "MSW Incineration Project in Guanzhuang, Tianjin City" whose baseline study, monitoring and verification plan and project design document were prepared by Global Climate Change Institute (GCCI) of Tsinghua University, Energy Systems International and Tianjin Taida Environmental Protection Co. Ltd.

This methodology also refers to the approved baseline and monitoring methodology:

- AM0013 "Avoided methane emissions from organic waste-water treatment";
- Approved small-scale methodology AMS-I.D "Grid connected renewable electricity generation".

This methodology also refers to the latest approved versions of the following tools:

- "Tool to determine project emissions from flaring gases containing methane";
- "Tool for the demonstration and assessment of additionality";
- "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site";
- "Tool to calculate the emission factor for an electricity system".

For more information regarding the proposed new methodologies and the tools as well as their consideration by the CDM Executive Board (the Board) please refer to <http://cdm.unfccc.int/goto/MPappmeth>.

Selected approach from paragraph 48 of the CDM modalities and procedures

"Emissions from a technology that represents an economically attractive course of action, taking into account barriers to investment"

or

"Existing actual or historical emissions, as applicable".

Applicability

The methodology is applicable under the following conditions:

- The project activity involves one or a combination of the following waste treatment options for the fresh waste that in a given year would have otherwise been disposed of in a landfill:

  (a) A composting process in aerobic conditions;

  (b) Gasification to produce syngas and its use;

  (c) Anaerobic digestion with biogas collection and flaring and/or its use. The anaerobic digester processes only the waste for which emission reductions are claimed in this methodology. If the biogas is processed and upgraded to the quality of natural gas and it is distributed as energy via natural gas distribution grid, project activities may use approved methodology AM0053 in conjunction with this methodology. In such cases the baseline scenario identification procedure and additionality assessment shall be undertaken for the combination of the two components of the project activity i.e. biomethane emission avoidance and displacement of natural gas;

  (d) Mechanical/thermal treatment process to produce refuse-derived fuel (RDF)/stabilized biomass (SB) and its use. The thermal treatment process (dehydration) occurs under controlled conditions (up to 300 degrees Celsius). In case of thermal treatment process, the process shall generate a stabilized biomass that would be used as fuel or raw material in other industrial process. The physical and chemical properties of the produced RDF/SB shall be homogenous and constant over time;

  (e) Incineration of fresh waste for energy generation, electricity and/or heat. The thermal energy generated is either consumed on-site and/or exported to a nearby facility. Electricity generated is either consumed on-site, exported to the grid or exported to a nearby facility. The incinerator is rotating fluidized bed or circulating fluidized bed or hearth or grate type.

- In case of anaerobic digestion, gasification or RDF processing of waste, the residual waste from these processes is aerobically composted and/or delivered to a landfill;
- In case of composting, the produced compost is either used as soil conditioner or disposed of in landfills;
- In case of RDF/stabilized biomass processing, the produced RDF/stabilized biomass should not be stored in a manner that may result in anaerobic conditions before its use;
- If RDF/SB is disposed of in a landfill, project proponent shall provide degradability analysis on an annual basis to demonstrate that the methane generation, in the life-cycle of the SB is below 1% of related emissions. It has to be demonstrated regularly that the characteristics of the produced RDF/SB should not allow for re-absorption of moisture of more than 3%. Otherwise, monitoring

the fate of the produced RDF/SB is necessary to ensure that it is not subject to anaerobic conditions in its lifecycle;

- In the case of incineration of the waste, the waste should not be stored longer than 10 days. The waste should not be stored in conditions that would lead to anaerobic decomposition and, hence, generation of CH_4;
- The proportions and characteristics of different types of organic waste processed in the project activity can be determined, in order to apply a multiphase landfill gas generation model to estimate the quantity of landfill gas that would have been generated in the absence of the project activity;
- The project activity may include electricity generation and/or thermal energy generation from the biogas, syngas captured, RDF/stabilized biomass produced, combustion heat generated in the incineration process, respectively, from the anaerobic digester, the gasifier, RDF/stabilized biomass combustor, and waste incinerator. The electricity can be exported to the grid and/or used internally at the project site. In the case of RDF/SB produced, the emission reductions can be claimed only for the cases where the RDF/SB used for electricity and/or thermal energy generation can be monitored;
- Waste handling in the baseline scenario shows a continuation of current practice of disposing the waste in a landfill despite environmental regulation that mandates the treatment of the waste, if any, using any of the project activity treatment options mentioned above;
- The compliance rate of the environmental regulations during (part of) the crediting period is below 50%; if monitored compliance with the MSW rules exceeds 50%, the project activity shall receive no further credit, since the assumption that the policy is not enforced is no longer tenable;
- Local regulations do not constrain the establishment of RDF production plants/thermal treatment plants nor the use of RDF/stabilized biomass as fuel or raw material;
- In case of RDF/stabilized biomass production, project proponent shall provide evidences that no GHG emissions occur, other than biogenic CO_2, due to chemical reactions during the thermal treatment process (such as Chimney Gas Analysis report);
- The project activity does not involve thermal treatment process of neither industrial nor hospital waste;
- In case of waste incineration, if auxiliary fossil fuel is added into the incinerator, the fraction of energy generated by auxiliary fossil fuel is no more than 50% of the total energy generated in the incinerator.

This methodology is not applicable to project activities that involve capture and flaring of methane from existing waste in the landfill. This should be treated as a separate project activity due to the difference in waste characteristics of existing and fresh waste, which may have an implication on the baseline scenario determination.

Summary

This methodology addresses project activities where fresh waste (i.e. the organic matter present in new domestic, commercial waste, organic industrial waste[1] and municipal solid waste), originally intended for landfilling, is treated either through one or a combination of the following process: composting,

[1] This may include organic industrial sludge eg. organic sludge generated from the effluent treatment plant of a pulp and paper manufacturing process.

gasification, anaerobic digestion, RDF processing/thermal treatment without incineration, and incineration. The project activity avoids methane emissions by diverting organic waste from disposal at a landfill, where methane emissions are caused by anaerobic processes, and by displacing electricity/ thermal energy through the utilization of biogas, syngas captured, RDF/stabilized biomass produced from the waste, combustion heat generated in the incineration process. By treating the fresh waste through alternative treatment options these methane emissions are avoided from the landfill. The GHGs involved in the baseline and project activity are CO_2, CH_4 and N_2O.

II. BASELINE METHODOLOGY

Procedure for the selection of the most plausible baseline scenario

Step 1: Identification of alternative scenarios

Project participants should use Step 1 of the latest version of the "Tool for the demonstration and assessment of additionality", to identify all realistic and credible baseline alternatives. In doing so, relevant policies and regulations related to the management of landfill sites should be taken into account. Such policies or regulations may include mandatory landfill gas capture or destruction requirements because of safety issues or local environmental regulations.[2] Other policies could include local policies promoting productive use of landfill gas such as those for the production of renewable energy, or those that promote the processing of organic waste. In addition, the assessment of alternative scenarios should take into account local economic and technological circumstances.

National and/or sectoral policies and circumstances must be taken into account in the following ways:

- In Sub-step 1b of the "Tool for the demonstration and assessment of additionality", the project developer must show that the project activity is not the only alternative that is in compliance with all regulations (e.g. because it is required by law);
- Via the adjustment factor (AF) in the baseline emissions, which is based on the approved consolidated baseline methodology ACM0001 "Consolidated baseline methodology for landfill gas project activities", project developers must take into account that some of the methane generated in the baseline may be captured and destroyed to comply with regulations or contractual requirements;
- The project developer must monitor all relevant policies and circumstances at the beginning of each crediting period and adjust the baseline accordingly.

Alternatives for the disposal/treatment of the fresh waste in the absence of the project activity, i.e. the scenario relevant for estimating baseline methane emissions, to be analysed should include, *inter alia*:

M1: The project activity (i.e. composting, gasification, anaerobic digestion, RDF processing/thermal treatment without incineration of organic waste or incineration of waste) not implemented as a CDM project;

M2: Disposal of the waste at a landfill where landfill gas captured is flared;

[2] The project developer must bear in mind the relevant clarifications on the treatment of national and/or sectoral policies and regulations in determining a baseline scenario as per Annex 3 to the Executive Board 22nd meeting and any other forthcoming guidance from the Board on this subject.

M3: Disposal of the waste on a landfill without the capture of landfill gas.

If energy is exported to a grid and/or to a nearby industry, or used on-site realistic and credible alternatives should also be separately determined for:

- Power generation in the absence of the project activity;
- Heat generation in the absence of the project activity.

For power generation, the realistic and credible alternative(s) may include, *inter alia*:

P1: Power generated from by-product of one of the options of waste treatment as listed in M1 above, not undertaken as a CDM project activity;

P2: Existing or Construction of a new on-site or off-site fossil fuel fired cogeneration plant;

P3: Existing or Construction of a new on-site or off-site renewable based cogeneration plant;

P4: Existing or Construction of a new on-site or off-site fossil fuel fired captive power plant;

P5: Existing or Construction of a new on-site or off-site renewable based captive power plant;

P6: Existing and/or new grid-connected power plants.

For heat generation, the realistic and credible alternative(s) may include, *inter alia*:

H1: Heat generated from by-product of one of the options of waste treatment as listed in M1 above, not undertaken as a CDM project activity;

H2: Existing or Construction of a new on-site or off-site fossil fuel fired cogeneration plant;[3]

H3: Existing or Construction of a new on-site or off-site renewable based cogeneration plant;[4]

H4: Existing or new construction of on-site or off-site fossil fuel based boilers;

H5: Existing or new construction of on-site or off-site renewable energy based boilers;

H6: Any other source such as district heat;

H7: Other heat generation technologies (e.g. heat pumps or solar energy).

Step 2: Identify the fuel for the baseline choice of energy source taking into account the national and/or sectoral policies as applicable

Demonstrate that the identified baseline fuel is available in abundance in the host country and there is no supply constraint. In case of partial supply constraints (seasonal supply), the project participants may consider an alternative fuel that result in lowest baseline emissions during the period of partial supply.

Detailed justification shall be provided for the selected baseline fuel. As a conservative approach, the lowest carbon intensive fuel such as natural gas through out the period may be used.

Note: Steps 3 and 4 shall be applied for each component of the baseline, i.e. baseline for waste treatment, electricity generation and heat generation.

[3] Scenarios P2 and H2 are related to the same fossil fuel cogeneration plant.
[4] Scenarios P3 and H3 are related to the same renewable energy based cogeneration plant.

Step 3: Step 2 and/or Step 3 of the latest approved version of the "Tool for demonstration and assessment of additionality" shall be used to assess which of these alternatives should be excluded from further consideration (e.g. alternatives facing prohibitive barriers or those clearly economically unattractive).

Step 4: Where more than one credible and plausible alternative remains, project participants shall, as a conservative assumption, use the alternative baseline scenario that results in the lowest baseline emissions as the most likely baseline scenario. The least emission alternative will be identified for each component of the baseline scenario. In assessing these scenarios, any regulatory or contractual requirements should be taken into consideration.

Note: The methodology is only applicable if:

(a) The most plausible baseline scenario for the waste treatment component is identified as either the disposal of the waste in a landfill without capture of landfill gas (M3) or the disposal of the waste in a landfill where the landfill gas is partially captured and subsequently flared (M2);

(b) The most plausible baseline scenario for the energy component of the baseline scenario is one of the following scenarios described in Table 1 below.

Table 1: Combinations of baseline options and scenarios applicable to this methodology

Scenario	Baseline			Description of situation
	Waste	Electricity	Heat	
1	M2/M3	P4 or P6	H4	The disposal of the waste in a landfill site without capturing landfill gas or the disposal of the waste in a landfill site where the landfill gas is partly captured and subsequently being flared. The electricity is obtained from an existing/new fossil based captive power plant or from the grid and heat from an existing/new fossil fuel based boiler
2	M2/M3	P2	H2	The disposal of the waste in a landfill site without capturing landfill gas or the disposal of the waste in a landfill site where the landfill gas is partly captured and subsequently being flared. The electricity and/or heat are generated by an existing/new fossil fuel based cogeneration plant

Additionality

The additionality of the project activity shall be demonstrated and assessed using the latest version of the "Tool for the demonstration and assessment of additionality" agreed by the Board.[5]

[5] Please refer to: < http://cdm.unfccc.int/goto/MPappmeth>.

Barrier analysis for the various baseline options may include:

(i) Investment barrier: A number of other, financially more viable alternatives, to the project activity exist for treating municipal solid waste. The project proponent shall demonstrate this through the identification of the lowest tipping fee option. The tipping fee is the fee that has to be paid per ton of waste to be treated and disposed. The option requiring the least tipping fee reflects the fact that municipalities usually choose the cheapest disposal option within the restrictions set by the MSW Rules. The minimum tipping fee is calculated by using the same project IRR (internal rate of return) for all the options. All costs and income should be taken into account, including the income from electricity generation and fertilizer sale. All technical and financial parameters have to be consistent across all baseline options;

(ii) Technological barrier: The project technology is the most technologically advanced option of the baseline options. Other options are less technologically advanced alternatives to the project activity and involves lower risks due to the performance uncertainty and low market share. The project proponent should provide evidence of the state of development of the project technology in the country and document evidence of barriers to the implementation of more the project technology;

(iii) Common practice: The project proponent should provide evidence of the early stage of development of the project activity and that it is not common practice in the country. To this end, they should provide an analysis of waste management practices.

In the case of RDF/stabilized biomass production, a key uncertainty for additionality is the price of RDF/stabilized biomass could attain such level in the region that RDF/stabilized biomass will be produced. The RDF/stabilized biomass price will be directly affected by its demand and the availability of other substitute products. Another evaluation of the stabilized biomass price should be carried out at the end of each crediting period (if the renewable crediting period is to be selected).

Project boundary

The spatial extent of the project boundary is the site of the project activity where the waste is treated. This includes the facilities for processing the waste, on-site electricity generation and/or consumption, onsite fuel use, thermal energy generation, wastewater treatment plant and the landfill site. The project boundary does not include facilities for waste collection, sorting and transport to the project site.

In the case that the project provides electricity to a grid, the spatial extent of the project boundary will also include those plants connected to the energy system to which the plant is connected.

The **greenhouse gases** included in or excluded from the project boundary are shown in Table 2.

Table 2: Summary of gases and sources included in the project boundary, and justification/explanation where gases and sources are not included

	Source	Gas		Justification / Explanation
Baseline	Emissions from decomposition of waste at the landfill site	CH_4	Included	The major source of emissions in the baseline
		N_2O	Excluded	N_2O emissions are small compared to CH_4 emissions from landfills. Exclusion of this gas is conservative
		CO_2	Excluded	CO_2 emissions from the decomposition of organic waste are not accounted[a]
	Emissions from electricity consumption	CO_2	Included	Electricity may be consumed from the grid or generated onsite/offsite in the baseline scenario
		CH_4	Excluded	Excluded for simplification. This is conservative
		N_2O	Excluded	Excluded for simplification. This is conservative
	Emissions from thermal energy generation	CO_2	Included	If thermal energy generation is included in the project activity
		CH_4	Excluded	Excluded for simplification. This is conservative
		N_2O	Excluded	Excluded for simplification. This is conservative
Project Activity	On-site fossil fuel consumption due to the project activity other than for electricity generation	CO_2	Included	May be an important emission source. It includes vehicles used on-site, heat generation for mechanical/thermal treatment process, start up of the gasifier, auxiliary fossil fuels needed to be added into incinerator, etc
		CH_4	Excluded	Excluded for simplification. This emission source is assumed to be very small
		N_2O	Excluded	Excluded for simplification. This emission source is assumed to be very small
	Emissions from on-site electricity use	CO_2	Included	May be an important emission source. If electricity is generated from collected biogas/syngas, these emissions are not accounted for. CO_2 emissions from fossil based waste from RDF/stabilized biomass combustion to generate electricity to be used on-site are accounted for
		CH_4	Excluded	Excluded for simplification. This emission source is assumed to be very small
		N_2O	Excluded	Excluded for simplification. This emission source is assumed to be very small
	Emissions from thermal energy generation	CO_2	Included	If thermal energy generation is included in the project activity
		CH_4	Excluded	Excluded for simplification. This emission source is assumed to be very small
		N_2O	Excluded	Excluded for simplification. This emission source is assumed to be very small

[a] Project proponents wishing to neglect these emission sources shall follow the clarification in Annex 2 of EB 22 report which states that "magnitude of emission sources omitted in the calculation of project emissions and leakage effects (if positive) should be equal to or less than the magnitude of emission sources omitted in the calculation of baseline emissions".

	Source	Gas		Justification / Explanation
	Direct emissions from the waste treatment processes.	N_2O	Included	May be an important emission source for composting activities. N_2O can be emitted from incineration, Syngas[a] produced, anaerobic digestion of waste and RDF/stabilized biomass combustion
		CO_2	Included	CO_2 emissions from incineration, gasification or combustion of fossil based waste shall be included. CO_2 emissions from the decomposition or combustion of organic waste are not accounte[b]
		CH_4	Included	The composting process may not be complete and result in anaerobic decay. CH_4 leakage from the anaerobic digester and incomplete combustion in the flaring process are potential sources of project emissions. CH_4 may be emitted from stacks[a] from incineration, the gasification process and the RDF/stabilized biomass combustion
	Emissions from waste water treatment	CO_2	Excluded	CO_2 emissions from the decomposition of organic waste are not accounted[b]
		CH_4	Included	The wastewater treatment should not result in CH_4 emissions, such as in anaerobic treatment; otherwise accounting for these emissions should be done
		N_2O	Excluded	Excluded for simplification. This emission source is assumed to be very small

Project emissions

The project emissions in year *y* are:

$$PE_y = PE_{elec,y} + PE_{fuel,\ on\text{-}site,y} + PE_{c,y} + PE_{a,y} + PE_{g,y} + PE_{r,y} + PE_{i,y} + PE_{w,y} + PE_{co\text{-}firing,y} \quad (1)$$

Where:

PE_y	=	Is the project emissions during the year *y* (tCO_2e)
$PE_{elec,y}$	=	Is the emissions from electricity consumption on-site due to the project activity in year *y* (tCO_2e)
$PE_{fuel,\ on\text{-}site,y}$	=	Is the emissions on-site due to fuel consumption on-site in year *y* (tCO_2e)
$PE_{c,y}$	=	Is the emissions during the composting process in year *y* (tCO_2e)
$PE_{a,y}$	=	Is the emissions from the anaerobic digestion process in year *y* (tCO_2e)
$PE_{g,y}$	=	Is the emissions from the gasification process in year *y* (tCO_2e)
$PE_{r,y}$	=	Is the emissions from the combustion of RDF/stabilized biomass in year *y* (tCO_2e)

[b] CO_2 emissions from the combustion or decomposition of *biomass* (see definition by the EB in Annex 8 of the EB's 20[th] meeting report) are not accounted as GHG emissions. Where the combustion or decomposition of biomass under a CDM project activity results in a decrease of carbon pools, such stock changes should be considered in the calculation of emission reductions. This is not the case for waste treatment projects.

$PE_{i,y}$	=	Is the emissions from waste incineration in year *y* (tCO_2e)
$PE_{w,y}$	=	Is the emissions from wastewater treatment in year *y* (tCO_2e)
$PE_{co\text{-}firing,y}$	=	Is the emissions from thermal energy generation/electricity generation from on-site fossil fuel consumption during co-firing in year *y* (tCO_2e)

Emissions from electricity use on site ($PE_{elec,y}$)

Where the project activity involves electricity consumption, CO_2 emissions are calculated as follows:

$$PE_{elec,y} = EG_{PJ,FF,y} * CEF_{elec} \quad (2)$$

Where:

$EG_{PJ,FF,y}$	=	Is the amount of electricity generated in an on-site fossil fuel fired power plant or consumed from the grid as a result of the project activity, measured using an electricity meter (MWh)
CEF_{elec}	=	Is the carbon emissions factor for electricity generation in the project activity (tCO_2/MWh)

In cases where electricity is generated in an on-site fossil fuel fired power plant, project participants should use, as CEF_{elec}, the default emission factor for a diesel generator with a capacity of more than 200 kW for small-scale project activities (0.8 tCO_2/MWh, see AMS-I.D, Table I.D.1 in the simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories).

In cases where electricity is purchased from the grid, the emission factor CEF_{elec} should be calculated according to the "Tool to calculate the emission factor for an electricity system".

Note: Project emissions from electricity consumption do not need to be calculated in case this electricity is generated by the project activity from biogas, or syngas. In case of electricity generation from RDF/stabilized biomass or incineration, project emissions are estimated as per equations 12 and 13 or (14).

If auxiliary fossil fuels need to be added into incinerator, emissions from its use shall be estimated by using equation 3 below.

Emissions from fuel use on-site ($PE_{fuel,\ on\text{-}site,y}$)

Project participants shall account for CO_2 emissions from any on-site fuel combustion (other than electricity generation, e.g. vehicles used on-site, heat generation, for starting the gasifier, auxiliary fossil fuels need to be added into incinerator, heat generation for mechanical/thermal treatment process, etc.). Emissions are calculated from the quantity of fuel used and the specific CO_2-emission factor of the fuel, as follows:

$$PE_{fuel,\ on\text{-}site,y} = F_{cons,y} * NCV_{fuel} * EF_{fuel} \quad (3)$$

Where:

$PE_{fuel,\ on\text{-}site,y}$	=	Is the CO_2 emissions due to on-site fuel combustion in year *y* (tCO_2)
$F_{cons,y}$	=	Is the fuel consumption on site in year *y* (l or kg)
NCV_{fuel}	=	Is the net caloric value of the fuel (MJ/l or MJ/kg)
EF_{fuel}	=	Is the CO_2 emissions factor of the fuel (tCO_2/MJ)

Local values should be preferred as default values for the net calorific values and CO_2 emission factors. If local values are not available, project participants may use IPCC default values for the net calorific values and CO_2 emission factors.

Emissions from composting ($PE_{c,y}$)

$$PE_{c,y} = PE_{c,N2O,y} + PE_{c,CH4,y} \quad (4)$$

Where:

$PE_{c,N2O,y}$	=	Is the N_2O emissions during the composting process in year *y* (tCO_2e)
$PE_{c,CH4,y}$	=	Is the emissions during the composting process due to methane production through anaerobic conditions in year *y* (tCO_2e)

N_2O emissions

During the storage of waste in collection containers, as part of the composting process itself, and during the application of compost, N_2O emissions might be released. Based upon Schenk[6] and others, a total loss of 42 mg N_2O-N per kg composted dry matter can be expected (from which 26.9 mg N_2O during the composting process). The dry matter content of compost is around 50% up to 65%.

Based on these values, project participants should use a default emission factor of 0.043 kg N_2O per tonne of compost for $EF_{c,N2O}$ and calculate emissions as follows:[7]

$$PE_{c,N2O,y} = M_{compost,y} * EF_{c,N2O} * GWP_{N2O} \quad (5)$$

Where:

$PE_{c,N2O,y}$	=	Is the N_2O emissions from composting in year *y* (tCO_2e)
$M_{compost,y}$	=	Is the total quantity of compost produced in year *y* (tonnes/a)
$EF_{c,N2O}$	=	Is the emission factor for N_2O emissions from the composting process (tN_2O/t compost)
GWP_{N2O}	=	Is the Global Warming Potential of nitrous oxide, (tCO_2/tN_2O)

CH_4 emissions

During the composting process, aerobic conditions are neither completely reached in all areas nor at all times. Pockets of anaerobic conditions – isolated areas in the composting heap where oxygen concentrations are so low that the biodegradation process turns anaerobic – may occur. The emission behaviour of such pockets is comparable to the anaerobic situation in a landfill. This is a potential emission source for methane similar to anaerobic conditions which occur in unmanaged landfills. The duration of the composting process is less than the duration of the crediting period. This is because of the fact that the compost may be subject to anaerobic conditions during its end use, which is not foreseen that it could be monitored. Assuming a residence time for the compost in anaerobic conditions equal to the crediting period is conservative. Through pre-determined sampling procedures the percentage of waste that degrades under anaerobic conditions can be determined. Using this percentage, project methane emissions from composting are calculated as follows:

$$PE_{c,CH4,y} = MB_{composty} * S_{a,y} \quad (6)$$

[6] Manfred K. Schenk, Stefan Appel, Diemo Daum, "N_2O emissions during composting of organic waste", Institute of Plant Nutrition University of Hannover, 1997.

[7] Assuming 650 kg dry matter per ton of compost and 42 mg N_2O-N, and given the molecular relation of 44/28 for N_2O-N, an emission factor of 0.043 kg N_2O / tonne compost results.

Where:

$PE_{c,CH4,y}$	=	Is the project methane emissions due to anaerobic conditions in the composting process in year *y* (tCO_2e)
$S_{a,y}$	=	Is the share of the waste that degrades under anaerobic conditions in the composting plant during year *y* (%)
$MB_{compost,y}$	=	Is the quantity of methane that would be produced in the landfill in the absence of the composting activity in year *y* (tCO_2e). $MB_{compost,y}$ is estimated by multiplying MB_y (unit of MB_y is tCO_2e) estimated from equation 23 by the fraction of waste diverted, from the landfill, to the composting activity (f_c) relative to the total waste diverted from the landfill to all project activities (composting, gasification, anaerobic digestion and RDF/stabilized biomass, incineration)

Calculation of $S_{a,y}$

$S_{a,y}$ is determined by a combination of measurements and calculations. Bokhorst et al[8] and Richard et al[9] show that if oxygen content is below 5% - 7.5%, aerobic composting processes are replaced by anaerobic processes. To determine the oxygen content during the process, project participants shall measure the oxygen content according to a predetermined sampling scheme and frequency.

These measurements should be undertaken for each year of the crediting period and recorded each year. The percentage of the measurements that show an oxygen content below 10% is presumed to be equal to the share of waste that degrades under anaerobic conditions (i.e. that degrades as if it were landfilled), hence the emissions caused by this share are calculated as project emissions ex post on an annual basis:

$$S_{a,y} = S_{OD,y} / S_{total,y} \quad (7)$$

Where:

$S_{OD,y}$	=	Is the number of samples per year with an oxygen deficiency (i.e. oxygen content below 10%)
$S_{total,y}$	=	Is the total number of samples taken per year, where $S_{total,y}$ should be chosen in a manner that ensures the estimation of $S_{a,y}$ with 20% uncertainty at a 95% confidence level

The produced compost can either be used as soil conditioner or disposed of in landfills. In case it is disposed of in landfills, CH_4 emissions are estimated through equation 23 using estimated weights of each waste type ($A_{ci,x}$). In case it is used as soil conditioner, its fate should be monitored as per the provisions of the monitoring methodology to ensure that it is not eventually disposed of in landfills. Otherwise, it should be conservatively assumed that the compost is disposed of in landfills and accordingly emissions should be estimated as described above.

[8] Jan Bokhorst. Coen ter Berg – Mest & Compost Behandelen beoordelen & Toepassen (Eng: Manure & Compost – Treatment, judgement and use), Louis Bolk Instituut, Handbook under number LD8, Oktober 2001.

[9] Tom Richard, Peter B. Woodbury, Cornell composting, operating fact sheet 4 of 10, Boyce Thompson Institute for Plant Research at Cornell University Cornell University.

Emissions from anaerobic digestion ($PE_{a,y}$)

$$PE_{a,y} = PE_{a,l,y} + PE_{a,s,y} \quad (8)$$

Where:

$PE_{a,l,y}$	=	Is he CH_4 leakage emissions from the anaerobic digesters in year *y* (tCO_2e)
$PE_{a,s,y}$	=	Is the total emissions of N_2O and CH_4 from stacks of the anaerobic digestion process in year *y* (tCO_2e)

CH_4 Emissions from physical leakage from the anaerobic digester ($PE_{a,l,y}$)

A potential source of project emissions is the physical leakage of CH_4 from the anaerobic digester. Three options are provided for quantifying these emissions, in the following preferential order:

Option 1: Monitoring the actual quantity of the gas leakage;
Option 2: Applying an appropriate IPCC physical leakage default factor, justifying the selection:

$$PE_{a,l,y} = P_l * M_{a,y} \quad (9)$$

Where:

$PE_{a,l,y}$	=	Is the leakage of methane emissions from the anaerobic digester in year *y* (tCO_2e)
P_l	=	Is the physical leakage factor from a digester (fraction)
$M_{a,y}$	=	Is the total quantity of methane produced by the digester in year *y* (tCO_2e)

Option 3: Applying a physical leakage factor of zero where advanced technology used by the project activity prevents any physical leakage. In such cases, the project proponent must provide the DOE with the details of the technology to prove that the zero leakage factor is justified.

Emissions from anaerobic digestion stacks ($PE_{a,s,y}$)

Biogas produced from the anaerobic digestion process may be either flared or used for energy generation. The final stack emissions (either from flaring or energy generation process) are monitored from the final stack and estimated as follows:

$$PE_{a,s,y} = SG_{a,y} * MC_{N2O,a,y} * GWP_{N2O} + SG_{a,y} * MC_{CH4,a,y} * GWP_{CH4} \quad (10)$$

Where:

$PE_{a,s,y}$	=	Is the total emissions of N_2O and CH_4 from stacks of the anaerobic digestion process in year *y* (tCO_2e)
$SG_{a,y}$	=	Is the total volume of stack gas from the anaerobic digestion in year *y* (m^3/yr)
$MC_{N2O,a,y}$	=	Is the monitored content of nitrous oxide in the stack gas from anaerobic digestion in year *y* (tN_2O/m^3)
GWP_{N2O}	=	Is the Global Warming Potential of nitrous oxide (tCO_2e/tN_2O)
$MC_{CH4,a,y}$	=	Is the monitored content of methane in the stack gas from anaerobic digestion in year *y* (tCH_4/m^3)
GWP_{CH4}	=	Is the Global Warming Potential of methane (tCO_2e/tCH_4)

Emissions from gasification ($PE_{g,y}$) or combustion of RDF/Stabilized Biomass ($PE_{r,y}$) or waste incineration($PE_{i,y}$)

The stack gas from the gasification process and the combustion of RDF[10] may contain small amounts of methane and nitrous oxide. Moreover, fossil-based waste CO_2 emissions from the gasification process and the combustion of RDF should be accounted for.

$$PE_{g/r/i,y} = PE_{g/r/i,f,y} + PE_{g/r/i,s,y} \quad (11)$$

Where:

$PE_{g/r/i,f,y}$	=	Is the fossil-based waste CO_2 emissions from gasification, waste incineration or RDF/stabilized biomass combustion in year y (tCO_2e)
$PE_{g/r/i,s,y}$	=	Is the N_2O and CH_4 emissions from the final stacks from gasification, waste incineration or RDF/stabilized biomass combustion in year y (tCO_2e)

Emissions from fossil-based waste ($PE_{g/r/i,f,y}$)

The CO_2 emissions are calculated based on the monitored amount of fossil-based waste fed into the gasifier, waste incineration plant or RDF/stabilized biomass combustion, the fossil-derived carbon content, and combustion efficiency. The calculation of CO_2 derived from gasification/incineration of waste of fossil origin and combusting RDF/stabilized biomass including waste of fossil origin, is estimated using either of the following options:

Option 1:

$$PE_{g/r/i,f,y} = \sum_i A_i \times CCW_i \times FCF_i \times EF \times \frac{44}{12} \quad (12)$$

Where:

$PE_{g/r/i,f,y}$	=	Is the fossil-based waste CO_2 emissions from gasification/RDF-combustion/waste incineration in year y (tCO_2e)
A_i	=	Is the amount of waste type i fed into the gasifier or RDF/stabilized biomass combustor or into the waste incineration plant (t/yr)
CCW_i	=	Is the fraction of carbon content in waste type i (fraction)
FCF_i	=	Is the fraction of fossil carbon in total carbon of waste type *i* (fraction)
EF	=	Is the combustion efficiency for waste (fraction)
44/12	=	Is the conversion factor (tCO_2/tC)

The amount of waste type i fed into the gasifier or RDF/stabilized biomass combustor or into the waste incineration plant (A_i) will be continuously monitored or calculated as per the following equation:

$$A_i = A_{MSW,y} \square \frac{\sum_{n=1}^{z} p_{n,i,y}}{z} \quad (13)$$

[10] RDF can be combusted to produce electricity, thermal energy or both (cogeneration).

Where:

A_i	=	Is the amount of waste type *i* fed into the gasifier or RDF/stabilized biomass combustor or into the waste incineration plant (t/yr)
$A_{MSW,y}$	=	Is the amount of MSW fed into the gasifier or RDF/stabilized biomass combustor or into the waste incineration plant (t/yr)
pn,j,y	=	Is the weight fraction of the waste type *i* in the sample n collected during the year *y*
Z	=	Number of samples collected during the year *y*

Option 2

$$PE_{g/r/i,f,y} = A_{MSW,y} \times FCF_{MSW} \times EF \times \frac{44}{12} \quad \textbf{(14)}$$

Where:

$PE_{g/r/i,f,y}$	=	Is the fossil-based waste CO_2 emissions from gasification/RDF-combustion/waste incineration in year *y* (tCO_2e)
$A_{MSW,y}$	=	Is the amount of MSW fed into the gasifier or RDF/stabilized biomass combustor or into the waste incineration plant(t/yr)
FCF_{MSW}	=	Is the fraction of fossil carbon in MSW (fraction)
EF	=	Is the combustion efficiency for waste (fraction)
44/12	=	Is the conversion factor (tCO_2/tC)

Emissions from gasification stacks or RDF/stabilized biomass combustion or waste incineration ($PE_{g/r/i,s,y}$)

Emissions of N2O and CH4 may be estimated from either of the options given below:

Option 1:

$$PE_{g/r/i,s,y} = SG_{g/r,y} * MC_{N2O,g/r/i,y} * GWP_{N2O} + SG_{g/r/i,y} * MC_{CH4,g/r/i,y} * GWP_{CH4} \quad \textbf{(15)}$$

Where:

$PE_{g/r/i,s,y}$	=	Is the total emissions of N_2O and CH_4 from gasification, waste incineration or RDF/stabilized biomass combustion in year *y* (tCO_2e)
$SG_{g/r/i,y}$	=	Is the total volume of stack gas from gasification, waste incineration or RDF/stabilized biomass combustion in year *y* (m3/yr)
$MC_{N2O,g/r/i,y}$	=	Is the monitored content of nitrous oxide in the stack gas from gasification, waste incineration or RDF/stabilized biomass combustion in year *y* (tN2O/m3)
GWP_{N2O}	=	Is the Global Warming Potential of nitrous oxide (tCO_2e/tN_2O)
$MC_{CH4,g/r/i,y}$	=	Is the monitored content of methane in the stack gas from gasification, waste incineration or RDF/stabilized biomass combustion in year *y* (tCH_4/m^3)
GWP_{CH4}	=	Is the Global Warming Potential of methane (tCO_2e /tCH_4)

Option 2:

$$PE_{g/r/i,s,y} = Q_{biomass,y} \cdot (EF_{N2O} \cdot GWP_{N2O} + EF_{CH4} \cdot GWP_{CH4}) \cdot 10^{-3} \quad (16)$$

Where:

$Q_{biomass,y}$	=	Is the amount of waste gasified, incinerated or RDF/stabilized biomass combusted in year *y* (tonnes/yr)
EF_{N2O}	=	Is the aggregate N_2O emission factor for waste combustion (kgN_2O/tonne of waste)
EF_{CH4}	=	Is the aggregate CH_4 emission factor for waste combustion ($kgCH_4$/tonne of waste)

Tables 5.4 and 5.3, chapter 5, volume 5 of IPCC 2006 guidelines should be used to estimate EF_{N2O} and EF_{CH4} , respectively.

In case the RDF/stabilized biomass is used offsite, N_2O and CH_4 emissions should be accounted for as leakage and estimated as per one of the options given above.

If IPCC default emission factor is used, a conservativeness factor should be applied to account for the high uncertainty of the IPCC default values. The level of the conservativeness factor depends on the uncertainty range of the estimate for the IPCC default N_2O and CH_4 emission factor. Project participants shall select the appropriate conservativeness factor from Table 3 below and shall multiply the estimate for the N_2O/CH_4 emission factor with the conservativeness factor.

Table 3: Conservativeness factors

Estimated uncertainty range (%)	Assigned uncertainty band (%)	Conservativeness factor where higher values are more conservative
Less than or equal to 10	7	1.02
Greater than 10 and less than or equal to 30	20	1.06
Greater than 30 and less than or equal to 50	40	1.12
Greater than 50 and less than or equal to 100	75	1.21
Greater than 100	150	1.37

Emissions from wastewater treatment ($PE_{w,y}$)

If the project activity includes wastewater release, methane emissions shall be estimated. If the wastewater is treated using aerobic treatment process, the CH_4 emissions from wastewater treatment are assumed to be zero. If wastewater is treated anaerobically or released untreated, CH_4 emissions are estimated as follows:

$$PE_{CH4,w,y} = Q_{COD,y} \cdot P_{COD,y} \cdot B_0 \cdot MCF_p \quad (17)$$

Where:

$PE_{CH4,w,y}$	=	Methane emissions from the wastewater treatment in year *y* (tCH_4/y)
$Q_{COD,y}$	=	Amount of wastewaster treated anaerobically or released untreated from the project activity in year *y* (m3/yr), which shall be measured monthly and aggregately annually
$P_{COD,y}$	=	Chemical Oxygen Demand (COD) of wastewaster ($tCOD/m^3$), which will be measured monthly and averaged annually

B_0	=	Maximum methane producing capacity ($tCH_4/tCOD$)
MCF_p	=	Methane conversion factor (fraction), preferably local specific value should be used. In absence of local values, MCF_p default values can be obtained from table 6.3, chapter 6, volume 4 from IPCC 2006 guidelines

IPCC 2006 guidelines specifies the value for B_0 as 0.25 kg CH_4/kg COD. Taking into account the uncertainty of this estimate, project participants should use a value of 0.265 kg CH_4/kg COD as a conservative assumption for B_o.

In case of all the CH_4 are emitted into air directly, then:

$$PE_{w,y} = PE_{CH4,w,y} \cdot GWP_{CH4} \quad \textbf{(18)}$$

If flaring occurs, the "Tool to determine project emissions from flaring gases containing methane" should be used to estimate methane emissions. In this case, $PE_{CH4,w,y}$ will be calculated ex-ante as per equation 15, and then monitored during the crediting period.

Emissions from thermal energy generation/electricity generation (from on-site fossil fuel consumption during co-firing) **($PE_{co\text{-}firing,y}$)**

Project participants shall account for CO_2 emissions associated to thermal energy generation/electricity if any from any on-site fossil fuel combustion during co-firing with waste (other than electricity use as mentioned above ($PE_{elec,y}$) and from fuel use on-site ($PE_{fuel,\ on\text{-}site,y}$)) and is calculated from the quantity of fossil fuel used for thermal energy generation/electricity generation and the specific CO_2 emission factor of the fossil fuel, as follows:

$$PE_{co\text{-}firing,y} = F_{co\text{-}firing,y} * NCV_{co\text{-}firing} * EF_{co\text{-}firing} \quad \textbf{(19)}$$

Where:

$PE_{co\text{-}firing,y}$	=	Is the CO_2 emissions due to thermal energy generation/electricity from on-site fossil fuel combustion in year *y* (tCO_2)
$F_{co\text{-}firing,y}$	=	Is the fossil fuel consumption for thermal energy generation/electricity in year *y* (l or kg)
$NCV_{co\text{-}firing}$	=	Is the net caloric value of the fossil fuel used for thermal energy generation (MJ/l or MJ/kg)
$EF_{co\text{-}firing}$	=	Is the CO_2 emissions factor of the fossil fuel used for thermal energy generation/electricity (tCO_2/MJ)

Baseline emissions

To calculate the baseline emissions project participants shall use the following equation:

$$BE_y = (MB_y - MD_{reg,y}) + BE_{EN,y} \quad \textbf{(20)}$$

Where:

BE_y	=	Is the baseline emissions in year *y* (tCO_2e)
MB_y	=	Is the methane produced in the landfill in the absence of the project activity in year *y* (t_4CO_2e)

$MD_{reg,y}$	=	Is methane that would be destroyed in the absence of the project activity in year *y* (t_4CO_2e)
$BE_{EN,y}$	=	Baseline emissions from generation of energy displaced by the project activity in year *y* (tCO_2e)

Adjustment Factor (AF)

In cases where regulatory or contractual requirements do not specify $MD_{reg,y}$, an Adjustment Factor (AF) shall be used and justified, taking into account the project context. In doing so, the project participant should take into account that some of the methane generated by the landfill may be captured and destroyed to comply with other relevant regulations or contractual requirements, or to address safety and odour concerns.

$$MD_{reg,y} = MB_y * AF \quad \textbf{(21)}$$

Where:

AF	=	Is Adjustment Factor for MB_y (%)

The parameter AF shall be estimated as follows:

- In cases where a specific system for collection and destruction of methane is mandated by regulatory or contractual requirements, the ratio between the destruction efficiency of that system and the destruction efficiency of the system used in the project activity shall be used;
- In cases where a specific percentage of the "generated" amount of methane to be collected and destroyed is specified in the contract or mandated by the regulation, this percentage divided by an assumed efficiency for the collection and destruction system used in the project activity shall be used.

The 'Adjustment Factor' shall be revised at the start of each new crediting period taking into account the amount of GHG flaring that occurs as part of common industry practice and/or regulation at that point in the future.

Rate of compliance

In cases where there are regulations that mandate the use of one of the project activity treatment options and which is not being enforced, the baseline scenario is identified as a gradual improvement of waste management practices to the acceptable technical options expected over a period of time to comply with the MSW Management Rules. The adjusted baseline emissions ($BE_{y,a}$) are calculated as follows:

$$BE_{y,a} = BE_y * (1 - RATE^{Compliance}{}_y) \quad \textbf{(22)}$$

Where:

BE_y	=	Is the CO_2-equivalent emissions as determined from equation 14
$RATE^{Compliance}{}_y$	=	Is the state-level compliance rate of the MSW Management Rules in that year *y*. The compliance rate shall be lower than 50%; if it exceeds 50% the project activity shall receive no further credit

In such cases $BE_{y,a}$ should replace BE_y in Equation (25) to estimate emission reductions.

The compliance ratio $RATE^{Compliance}_y$ shall be monitored *ex post* based on the official reports for instance annual reports provided by municipal bodies.

Methane generation from the landfill in the absence of the project activity (MB_y)

The amount of methane that is generated each year (MB_y) is calculated as per the latest version of the approved "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site" considering the following additional equation:

$$MB_y = BE_{CH4,SWDS,y} \quad (23)$$

Where:

$BE_{CH4,SWDS,y}$ = Is the methane generation from the landfill in the absence of the project activity at year *y* that is methane emissions avoided during the year *y* from preventing waste disposal at the solid waste disposal site during the period from the start of the project activity to the end of the year y (tCO_2e) as calculated in the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site". The tool estimates methane generation adjusted for, using adjustment factor (f), any landfill gas in the baseline that would have been captured and destroyed to comply with relevant regulations or contractual requirements, or to address safety and odor concerns. As this is already accounted for in equation 19, in this methodology, "f" in the tool shall be assigned a value 0

Note: Where for a particular year it cannot be demonstrated that the waste would have been disposed of in the landfill, the waste quantities prevented from disposal ($W_{j,x}$) in the tool should be assigned a value 0 (zero).

$A_{j,x}$ = Is the amount of organic waste type *j* prevented from disposal in the landfill in the year *x* (tonnes/year), this is the value to be used for variable $W_{j,x}$ in the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"

Baseline emissions from generation of energy

Scenario 1 (see Table 1 above)

$$BE_{EN,y} = BE_{elec,y} + BE_{thermal,y} \quad (24)$$

Where:

$BE_{elec,y}$ = Is the baseline emissions from electricity generated utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity and exported to the grid or displacing onsite/offsite fossil fuel captive power plant (tCO_2e)

$BE_{thermal,y}$ = Is the baseline emissions from thermal energy produced utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity displacing thermal energy from onsite/offsite fossil fuel fueled boiler (tCO_2e)

$$BE_{elec,y} = EG_{d,y} * CEF_d \quad (25)$$

Where:

$EG_{d,y}$	=	Is the amount of electricity generated utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity and exported to the grid or displacing onsite/offsite fossil fuel captive power plant during the year *y* (MWh)
CEF_d	=	Is the carbon emissions factor for the displaced electricity source in the project scenario (tCO_2/MWh)

Determination of CEF_d

Where the project activity involves electricity generation from the biogas/syngas/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel , CEF_d should be chosen as follows:

- In case the generated electricity from the biogas/syngas/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel displaces electricity that would have been generated by an on-site/off-site fossil fuel fired captive power plant in the baseline, project proponents shall estimate the emission factor as follows:

$$CEF_d = \frac{EF_{fuel,b}}{\varepsilon_{gen,b}} * 3.6 \qquad \textbf{(26)}$$

Where:

$EF_{fuel,b}$	=	Is the emission factor of baseline fossil fuel used, as identified in the baseline scenario identification procedure, expressed in tCO_2/GJ
$\varepsilon_{gen,b}$	=	Is the efficiency of baseline power generation plant
3.6	=	Equivalent of GJ energy in a MWh of electricity

To estimate electricity generation efficiency, project participants may use the highest value among the following three values as a conservative approach:

(1) Measured efficiency prior to project implementation;

(2) Measured efficiency during monitoring;

(3) Data from manufacturer for efficiency at full load;

(4) Default efficiency of 60%.

- In case the generated electricity from the biogas/syngas/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel displaces electricity that would have been generated by other power plants in the grid in the baseline, CEF_d should be calculated according to the “Tool to calculate the emission factor for an electricity system”.

$$BE_{thermal,y} = \frac{Q_y}{\varepsilon_{boiler} \cdot NCV_{fuel}} \cdot EF_{fuel,b} \qquad \textbf{(27)}$$

Where :

Q_y	=	The quantity of thermal energy produced utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity displacing thermal energy from onsite/offsite fossil fuel fueled boiler during the year *y* in GJ
ε_{boiler}	=	The energy efficiency of the boiler used in the absence of the project activity to generate the thermal energy
NCV_{fuel}	=	Net calorific value of fuel, as identified through the baseline identification procedure, used in the boiler to generate the thermal energy in the absence of the project activity in GJ per unit of volume or mass
$EF_{fuel,b}$	=	Emission factor of the fuel, as identified through the baseline identification procedure, used in the boiler to generate the thermal energy in the absence of the project activity in tons CO_2 per unit of volume or mass of the fuel

To estimate boiler efficiency, project participants may choose between the following two options:

Option A:

Use the highest value among the following three values as a conservative approach:

(1) Measured efficiency prior to project implementation;

(2) Measured efficiency during monitoring;

(3) Manufacturer's information on the boiler efficiency.

Option B:

Assume a boiler efficiency of 100% based on the net calorific values as a conservative approach.

In determining the CO_2 emission factors (EF_{fuel}) of fuels, reliable local or national data should be used if available. Where such data is not available, IPCC default emission factors should be chosen in a conservative manner.

Scenario 2 (see Table 1 above):

Baseline emissions from electricity and heat cogeneration Baseline emissions from electricity and heat cogeneration are calculated by multiplying electricity ($EG_{d,y}$) and heat supplied (Qy) with the CO_2 emission factor of the fuel used by the cogeneration plant, as follows:

$$BE_{EN,y} = \frac{(EG_{d,y} \cdot 3.6) * 10^{-3} + Q_y}{\eta_{cogen}} \cdot EF_{fuel,c} \qquad \textbf{(28)}$$

Where:

3.6	=	Conversion factor, expressed as TJ/GWh
$EF_{fuel,c}$	=	Is the CO_2 emission factor per unit of energy of the fuel that would have been used in the baseline cogeneration plant in (tCO_2/TJ), obtained from reliable local or national data if available, otherwise, taken from the country specific IPCC 2006 default emission factors
Qy	=	The quantity of thermal energy produced utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity displacing thermal energy from cogeneration during the year *y* in TJ
$EG_{d,y}$	=	Is the amount of electricity generated utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity displacing onsite/offsite cogeneration plant during the year *y* in GWh
η_{Cogen}	=	The efficiency of cogeneration plant that would have been used in the absence of the project activity

Efficiency of the cogeneration plant (η_{Cogen}) shall be one of the following:

(1) Highest of the measured efficiencies of similar plants;

(2) Highest of the efficiency values provided by two or more manufacturers for similar plants; or

(3) Maximum efficiency of 90%, based on net calorific values.

Leakage

The sources of leakage considered in the methodology are CO_2 emissions from off-site transportation of waste materials in addition to CH_4 and N_2O emissions from the residual waste from the anaerobic digestion, gasification processes and processing/combustion of RDF. In case of waste incineration, leakage emissions from residual waste of MSW incinerator should be accounted for. Positive leakage that may occur through the replacement of fossil-fuel based fertilizers with organic composts are not accounted for. Leakage emissions should be estimated from the following equation:

$$L_y = L_{t,y} + L_{r,y} + L_{i,y} + L_{s,y} \quad \textbf{(29)}$$

Where:

$L_{t,y}$	=	Is the leakage emissions from increased transport in year *y* (tCO_2e)
$L_{r,y}$	=	Is the leakage emissions from the residual waste from the anaerobic digester, the gasifier, the processing/combustion of RDF/stabilized biomass, or compost in case it is disposed of in landfills in year *y* (tCO_2e)
$L_{i,y}$	=	Is the leakage emissions from the residual waste from MSW incinerator in year *y* (tCO_2e)
$L_{s,y}$	=	Is the leakage emissions from end use of stabilized biomass

Emissions from transportation ($L_{t,y}$)

The project may result in a change in transport emissions. This would occur when the waste is transported from waste collecting points, in the collection area, to the treatment facility, instead of to existing landfills. When it is likely that the transport emissions will increase significantly, such emissions should be incorporated as leakage. In this case, project participants shall document the following data in the

CDM-PDD: an overview of collection points from where the waste will be collected, their approximate distance (in km) to the treatment facility, existing landfills and their approximate distance (in km) to the nearest end-user.

For calculations of the emissions, IPCC default values for fuel consumption and emission factors may be used. The CO_2 emissions are calculated from the quantity of fuel used and the specific CO_2-emission factor of the fuel for vehicles i to n, as follows:

$$L_{t,y} = \sum_{i}^{n} NO_{vehicles,i,y} * DT_{i,y} * VF_{cons,i} * NCV_{fuel} * D_{fuel} * EF_{fuel} \quad (30)$$

Where:

$NO_{vehicles,i,y}$	=	Is the number of vehicles for transport with similar loading capacity
$DT_{i,y}$	=	Is the average additional distance travelled by vehicle type i compared to baseline in year *y* (km)
$VF_{cons,i}$	=	Is the vehicle fuel consumption in litres per kilometre for vehicle type *i* (l/km)
NCV_{fuel}	=	Is the Calorific value of the fuel (MJ/Kg or other unit)
D_{fuel}	=	Is the fuel density (kg/l), if necessary
EF_{fuel}	=	Is the Emission factor of the fuel (tCO_2/MJ)

For transport of compost to the users, the same formula applies.

Emissions from residual waste from anaerobic digester, gasifier, and processing/combustion of RDF/stabilized biomass or compost in case it is disposed of in landfills ($L_{r,y}$)

For the residual waste from the anaerobic digestion, the gasification processes, and the processing/combustion of RDF/stabilized biomass the weight ($A_{ci,x}$) of each of the waste types *i* in year *x* should be estimated. Leakage emissions from this residual waste should be estimated using the determined weights as follows:

In case the residual waste is aerobically treated through composting, emissions shall be estimated as follows:

- N_2O emissions shall be estimated using equation 5 replacing $M_{compost,y}$ by the sum of the weights of different waste types ($A_{ci,x}$);
- CH_4 emissions shall be estimated using the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site". The value of variable $W_{j,x}$ is $A_{ci,x}$. The result should be multiplied by S_{LE} factor. S_{LE} is estimated as follows:

$$S_{LE} = S_{OD,LE} / S_{LE,total} \quad (31)$$

Where:

$S_{OD,LE}$	=	Is the number of samples per year with an oxygen deficiency (i.e. oxygen content below 10%)
$S_{LE,total}$	=	Is the total number of samples taken per year, where S_{total} should be chosen in a manner that ensures the estimation of S_a with 20% uncertainty at a 95% confidence level
$A_{ci,x}$	=	Weight of each of the waste types i in year *x*

In case the residual waste or the compost is delivered to a landfill, CH_4 emissions are estimated through equation 23 using estimated weights of each waste type ($A_{ci,x}$). As a conservative approach, residual waste or compost can be assumed to only include a single waste type that was fed into the process (anaerobic digestion, the gasification processes, and the processing/combustion of RDF/stabilized biomass) which results in less emission reductions.

Leakage Emissions from the residual waste from MSW incineration ($L_{i,y}$)

In case of waste incineration, leakage emissions from the residual waste of MSW incinerator should be accounted for using the following equations:

If the residual waste from the incinerator contains up to 5% residual carbon then:

$$L_{i,y} = A_{residual} . FC_{residual} \cdot \frac{44}{12} \tag{32}$$

If the residual waste from the incinerator contains more than 5% residual carbon[11] then:

$$L_{i,y} = A_{residualy} \cdot 0.05 \cdot \frac{44}{12} + A_{residual,y} \cdot (FC_{residual} - 0.05) \cdot \frac{16}{12} \cdot 21 \tag{33}$$

Where:

$L_{i,y}$	=	Is the leakage emissions from the residual waste of MSW incinerator in year *y* (tCO_2e)
$A_{residual,y}$	=	Is the amount of the residual waste from the incinerator (t/yr)
$FC_{residual}$	=	Is the fraction of residual carbon contained in the residual waste (%)
$\frac{44}{12}$	=	Is a factor to convert from Carbon to Carbon Dioxide
$\frac{16}{12}$	=	Is factor to convert from Carbon to methane
21	=	Is the Global Warming Potential of methane (tCO_2/tCH_4)

Off-site Emissions from end use of the stabilized biomass ($L_{s,y}$)

Project proponents have to demonstrate that there is no emission associated to non-combustion end-use of stabilized biomass (SB) and that the SB is indeed stabilized. If SB is used as raw material in furniture, fertilizers or ceramic industry, no leakage other than transportation change is expected. Unless the project proponent can prove that SB for furniture industry will not be combusted in the end of its life cycle, to be conservative, the emissions will be considered using the same rationale as per equations 12 and 13 or 14.

For amount of RDF/stabilized biomass used off-site for which no sale invoices can be provided, and in cases where the project proponents cannot provide analysis of the capacity of RDF/stabilized biomass for moisture absorption, leakage emissions should be accounted for as follows:

[11] In this case, it is assumed that all the carbon in the residual waste will be converted to methane. This provision is included to offer an incentive for Project Proponents to operate their incinerator efficiently.

Quantities of different types of waste input ($A_{j,x}$) to the RDF/biomass processing should be adjusted by an annual adjustment factor SA_y as follows:

$$A_{s,j,x} = SA_y * A_{j,x} \tag{34}$$

$$SA_y = \left(\frac{R_n}{R_t}\right) \tag{35}$$

Where:

SA_y	=	Is an adjustment factor for a specific year
R_n	=	Is the weight of RDF/stabilized biomass sold offsite for which no sale invoices can be provided (t/yr)
R_t	=	Is the total weight of RDF/stabilized biomass produced (t/yr)

Annual leakage methane emissions ($L_{s,y}$) is calculated as per the latest version of the approved "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site", considering the following additional equation and using the adjusted weights ($A_{s,j,x}$) of waste input to the RDF/stabilized biomass processing facility for variable $W_{j,x}$:

$$L_{s,y} = BE_{CH4,SWDS,y} \tag{36}$$

Where:

$BE_{CH4,SWDS,y}$	=	Is the methane generation from the landfill in the absence of the project activity, calculated as per the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"

Emission Reductions

To calculate the emission reductions the project participant shall apply the following equation:

$$ER_y = BE_y - PE_y - L_y \tag{37}$$

Where:

ER_y	=	Is the emissions reductions in year y (t CO_2e)
BE_y	=	Is the emissions in the baseline scenario in year y (tCO_2e)
PE_y	=	Is the emissions in the project scenario in year y (tCO_2e)
L_y	=	Is the leakage in year y (tCO_2e)

If the sum of PE_y and L_y is smaller than 1% of BE_y in the first full operation year of a crediting period, the project participants may assume a fixed percentage of 1% for PE_y and L_y combined for the remaining years of the crediting period.

In the case that overall negative emission reductions arise in a year, ERs are not issued to project participants for the year concerned and in subsequent years, until emission reductions from subsequent years have compensated the quantity of negative emission reductions from the year concerned. (For example: if negative emission reductions of 30 tCO_2e occur in the year t and positive emission reductions of 100 tCO_2e occur in the year t+1, 0 CERs are issued for year t and only 70 CERs are issued for the year t+1.)

Changes required for methodology implementation in 2nd and 3rd crediting periods

No changes in the procedure are expected. If there have been changes in the regulations with respect to waste disposal or industries practices, the adjustment factor AF in the baseline emissions (used in equation 18 above) shall be re-estimated. Note, that adjustment will be needed at the time of renewal of the crediting period.

Data and parameters not monitored

Data / Parameter:	$EF_{c,N2O}$
Data unit:	tN2O/tonnes of compost
Description:	Emission factor for N_2O emissions from the composting process
Source of data:	Research literature
Measurement procedures (if any):	*Ex ante*
Any comment:	Default value of 0.043kg-N_2O/t-compost, after Schenk et al, 1997. The value itself is highly variable, but reference data shall be used

Data / Parameter:	Bo
Data unit:	tCH_4/tCOD
Description:	Maximum methane producing capacity
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain.
Measurement procedures (if any):	
Any comment:	A default value of 0.265 tCH_4/tCOD may be used

Data / Parameter:	MCF_p
Data unit:	%
Description:	Methane conversion factor (fraction)
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Any comment:	Preferably local specific value should be used. In absence of local values, MCF_p default values can be obtained from table 6.3, chapter 6, volume 4 from IPCC 2006 guidelines

Data / Parameter:	ε_{boiler}
Data unit:	%
Description:	Energy Efficiency of boilers used for generating thermal energy in the absence of the project activity
Source of data:	Reference data or country specific data
Measurement procedures (if any):	To estimate boiler efficiency, project participants may choose between the following two options: Option A Use the highest value among the following three values as a conservative approach: 1. Measured efficiency prior to project implementation; 2. Measured efficiency during monitoring; 3. Manufacturer's information on the boiler efficiency. Option B Assume a boiler efficiency of 100% based on the net calorific values as a conservative approach.
Any comment:	Measured or estimated conservatively (e.g. using manufacturers' information on maximum efficiency). Applicable if baseline for exported energy is Scenario 1

Data / Parameter:	$\varepsilon_{gen,b}$
Data unit:	%
Description:	Energy Efficiency of power plant that would have generated electricity, in absence of the project activity.
Source of data:	Reference data or country specific data
Measurement procedures (if any):	To estimate electricity generation efficiency, project participants may use the highest value among the following three values as a conservative approach: 1. Measured efficiency prior to project implementation; 2. Measured efficiency during monitoring; 3. Data from manufacturer for efficiency at full load; 4. Default efficiency of 60%.
Any comment:	Applicable if baseline for exported energy is Scenario 1

Data / Parameter:	η_{Cogen}
Data unit:	%
Description:	Efficiency of cogeneration plant that would have been used, in absence of the project activity
Source of data:	Manufacturer's data or information from similar plant operators
Measurement procedures (if any):	Efficiency of the cogeneration plant, (η_{Cogen}) shall be one of the following: 1. Highest of the measured efficiencies of similar plants; 2. Highest of the efficiency values provided by two or more manufacturers for similar plants; or 3. Maximum efficiency of 90%, based on net calorific values
Any comment:	Applicable if baseline for energy generation is Scenario 2

Data / Parameter:	$EF_{fuel,b}$
Data unit:	tCO_2/MJ
Description:	Emission factor of baseline fossil fuel used in the boiler, as identified in the baseline scenario identification
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Any comment:	

Data / Parameter:	$EF_{fuel,c}$
Data unit:	tCO_2/MJ
Description:	Emission factor of baseline fossil fuel used in the cogeneration plant, as identified in the baseline scenario identification
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Any comment:	

III. MONITORING METHODOLOGY

Data and parameters monitored

Data / Parameter:	$EG_{PJ,FF,y}$
Data unit:	MWh
Description:	Amount of electricity generated in an on-site fossil fuel fired power plant or consumed from the grid as a result of the project activity
Source of data:	Electricity meter
Measurement procedures (if any):	
Monitoring frequency:	Continuous
QA/QC procedures:	Electricity meter will be subject to regular (in accordance with stipulation of the meter supplier) maintenance and testing to ensure accuracy. The readings will be double checked by the electricity distribution company
Any comment:	

Data / Parameter:	CEF_{elec}
Data unit:	tCO_2/MWh
Description:	Emission factor for the production of electricity in the project activity
Source of data:	Official utility documents
Measurement procedures (if any):	Calculated according to the "Tool to calculate the emission factor for an electricity system", or as diesel default factor according to AMS I.D, Table I.D.1, if the conditions of the table are fulfilled or according to data from captive power plant, if any
Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	Calculated as per appropriate methodology at start of crediting period
Any comment:	

Data / Parameter:	$F_{cons,y}$
Data unit:	mass or volume units of fuel
Description:	Fuel consumption on-site during year *y* of the crediting period
Source of data:	Purchase invoices and/or metering
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	The amount of fuel will be derived from the paid fuel invoices (administrative obligation)
Any comment:	This parameter includes the auxiliary fossil fuels that need to be added in the incinerator or used for mechanical or thermal treatment process

Data / Parameter:	NCV_{fuel}
Data unit:	MJ/mass or volume units of fuel
Description:	Net calorific value of fuel
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	
Any comment:	

Data / Parameter:	EF_{fuel}
Data unit:	tCO_2/MJ
Description:	Emission factor of the fuel
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	
Any comment:	

Data / Parameter:	$M_{compost,y}$
Data unit:	tonnes
Description:	Total quantity of compost produced in year *y*
Source of data:	Plant records
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	Weighed on calibrated scale; also cross check with sales of compost
Any comment:	The produced compost will be trucked off from site. All trucks leaving site will be weighed. Possible temporary storage of compost will be weighed as well or not taken into account for calculated carbon credits

Data / Parameter:	P_l
Data unit:	fraction
Description:	Leakage of methane emissions from anaerobic digester
Source of data:	IPCC or project participant
Measurement procedures (if any):	
Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	The value itself is highly variable, but reference data shall be used, as well as measurement by project participants
Any comment:	

Data / Parameter:	$M_{a,y}$
Data unit:	tCO_2/year
Description:	Total methane produced from anaerobic digester
Source of data:	Project participants
Measurement procedures (if any):	
Monitoring frequency:	Continuous
QA/QC procedures:	Data can be checked from usage records
Any comment:	This quantity is necessary to calculate the leakage of methane from the digester which has a default leakage of 15%

Data / Parameter:	$SG_{a,y}$
Data unit:	m^3/yr
Description:	Stack gas volume flow rate
Source of data:	Project participants
Measurement procedures (if any):	
Monitoring frequency:	Continuous or periodic (at least quarterly)
QA/QC procedures:	Maintenance and calibration of equipment will be carried out according to internationally recognised procedures. Where laboratory work is outsourced, one which follows rigorous standards shall be selected
Any comment:	The stack gas flow rate is either directly measured or calculated from other variables where direct monitoring is not feasible. Where there are multiple stacks of the same type, it is sufficient to monitor one stack of each type. The stack gas volume flow rate may be estimated by summing the inlet biogas and air flow rates and adjusting for stack temperature. Air inlet flow rate should be estimated by direct measurement using a flow meter

Data / Parameter:	$MC_{N2O,a,y}$
Data unit:	tN_2O/m^3
Description:	Concentration of N_2O in stack gas
Source of data:	Project participants
Measurement procedures (if any):	
Monitoring frequency:	At least quarterly
QA/QC procedures:	Maintenance and calibration of equipment will be carried out according to internationally recognised procedures. Where laboratory work is outsourced, one which follows rigorous standards shall be selected
Any comment:	More frequent sampling is encouraged

Data / Parameter:	$MC_{CH4,a,y}$
Data unit:	tCH_4/m^3
Description:	Concentration of CH_4 in stack gas
Source of data:	Project Participants
Measurement procedures (if any):	
Monitoring frequency:	At least quarterly
QA/QC procedures:	Maintenance and calibration of equipment will be carried out according to internationally recognised procedures. Where laboratory work is outsourced, one which follows rigorous standards shall be selected
Any comment:	More frequent sampling is encouraged

Data / Parameter:	$A_{MSW,y}$
Data unit:	tonnes/yr
Description:	Amount of MSW fed into the gasifier or RDF/stabilized biomass combustor or into the waste incineration plant
Source of data:	Project participants
Measurement procedures (if any):	Measured with calibrated scales/load cells
Monitoring frequency:	Continuously, aggregated at least annually
QA/QC procedures:	
Any comment:	

Data / parameter:	$P_{n,i,y}$
Data unit:	-
Description:	Weight fraction of the waste type *i* in the sample *n* collected during the year *y*
Source of data:	Sample measurements by project participants
Measurement procedures (if any):	
Monitoring frequency:	The size and frequency of sampling should be statistically significant with a maximum uncertainty range of 20% at a 95% confidence level. As a minimum, sampling should be undertaken four times per year
QA/QC procedures:	
Any comment:	

Data / Parameter:	z
Data unit:	-
Description:	Number of samples collected during the year *y*
Source of data:	Project participants
Measurement procedures (if any):	
Monitoring frequency:	Continuously, aggregated annually
QA/QC procedures:	
Any comment:	

Data / Parameter:	CCW_i
Data unit:	Fraction
Description:	Fraction of carbon content in waste type *i*
Source of data:	IPCC or other reference data
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	
Any comment:	

Data / Parameter:	FCF_i
Data unit:	fraction
Description:	Faction of fossil carbon in total carbon of waste type *i*
Source of data:	Sample measurements by project participants
Measurement procedures (if any):	The following standards should be used to estimate fossil carbon fraction of waste type *i:* • ASTM D6866-08: "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis"; • ASTM D7459-08: "Standard Practice for Collection of Integrated Samples for the Speciation of Biomass (Biogenic) and Fossil-Derived Carbon Dioxide Emitted from Stationary Emissions Sources"
Monitoring frequency:	The size and frequency of sampling should be statistically significant with a maximum uncertainty range of 20% at a 95% confidence level. As a minimum, sampling should be undertaken four times per year
QA/QC procedures:	
Any comment:	

Data / Parameter:	FCF_{MSW}
Data unit:	Fraction
Description:	Fraction of fossil carbon in MSW
Source of data:	Sample measurements by project participants
Measurement procedures (if any):	The following standards should be used: • ASTM D6866-08: "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis"; • ASTM D7459-08: "Standard Practice for Collection of Integrated Samples for the Speciation of Biomass (Biogenic) and Fossil-Derived Carbon Dioxide Emitted from Stationary Emissions Sources"
Monitoring frequency:	The size and frequency of sampling should be statistically significant with a maximum uncertainty range of 20% at a 95% confidence level. As a minimum, sampling should be undertaken four times per year. Samples need to be representative of all categories of waste. DOEs should check the consistency between the sample composition sent to labs for determining fossil carbon in waste and the actual waste received on site. Project proponents are required to keep records of the composition of the waste sample sent for testing. Lab results reports for fossil carbon should also include the composition of the waste sample that was tested
QA/QC procedures:	
Any comment:	

Data / Parameter:	EF
Data unit:	Fraction
Description:	Combustion efficiency for waste
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	
Any comment:	

Data / Parameter:	$SG_{g/r/i,y}$
Data unit:	m^3/yr
Description:	Total volume of stack gas from gasification, waste incineration or RDF/stabilized biomass combustion in year *y*
Source of data:	Project site
Measurement procedures (if any):	
Monitoring frequency:	Continuous or periodic (at least quarterly)
QA/QC procedures:	
Any comment:	The stack gas flow rate is either directly measured or calculated from other variables where direct monitoring is not feasible. Where there are multiple stacks of the same type, it is sufficient to monitor one stack of each type. The stack gas volume flow rate may be estimated by summing the inlet biogas and air flow rates and adjusting for stack temperature. Air inlet flow rate should be estimated by direct measurement using a flow meter

Data / Parameter:	$MC_{N2O,g/r/i,y}$
Data unit:	tN_2O/m^3
Description:	Monitored content of nitrous oxide in the stack gas from gasification, waste incineration or RDF combustion in year *y*
Source of data:	Project site
Measurement procedures (if any):	
Monitoring frequency:	At least quarterly
QA/QC procedures:	
Any comment:	More frequent sampling is encouraged

Data / Parameter:	$MC_{CH4,g/r/i,y}$
Data unit:	tCH_4/m^3
Description:	Monitored content of methane in the stack gas from gasification, waste incineration or RDF/stabilized combustion in year *y*
Source of data:	Project site
Measurement procedures (if any):	
Monitoring frequency:	At least quarterly
QA/QC procedures:	
Any comment:	More frequent sampling is encouraged

Data / Parameter:	MB_y
Data unit:	tCH_4
Description:	Methane produced in the landfill in the absence of the project activity in year *y*
Source of data:	Calculated as per the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"
Measurement procedures (if any):	As per the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"
Monitoring frequency:	As per the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"
QA/QC procedures:	As per the "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site"
Any comment:	-

Data / Parameter:	AF
Data unit:	%
Description:	Methane destroyed due to regulatory or other requirements
Source of data:	Local and/or national authorities
Measurement procedures (if any):	
Monitoring frequency:	At renewal of crediting period
QA/QC procedures:	Data are derived from or based upon local or national guidelines, so QA/QC-procedures for these data are not applicable
Any comment:	Changes in regulatory requirements, relating to the baseline landfill(s) need to be monitored in order to update the adjustment factor (AF), or directly MD_{reg}. This is done at the beginning of each crediting period

Data / Parameter:	$EG_{d,y}$
Data unit:	MWh
Description:	Amount of electricity generated utilizing the biogas/syngas collected/RDF/stabilized biomass/combustion heat from incineration/stabilized biomass co-fired with fossil fuel in the project activity displacing electricity in the baseline during the year *y*
Source of data:	Electricity meter
Measurement procedures (if any):	
Monitoring frequency:	Continuous
QA/QC procedures:	
Any comment:	

Data / Parameter:	CEF_d
Data unit:	tCO_2/MWh
Description:	Emission factor of displaced electricity by the project activity
Source of data:	Captive power plant: estimated as per equation 23. Grid: as per the "Tool to calculate the emission factor for an electricity system"
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	
Any comment:	

Data / Parameter:	$RATE^{Compliance}_{y}$
Data unit:	Number
Description:	Rate of compliance
Source of data:	Municipal bodies
Measurement procedures (if any):	The compliance rate is based on the annual reporting of the municipal bodies issuing these reports. The state-level aggregation involves all landfill sites in the country. If the rate exceeds 50%, no CERs can be claimed
Monitoring frequency:	Annual
QA/QC procedures:	
Any comment:	

Data / Parameter:	$NO_{vehicles,i,y}$
Data unit:	Number
Description:	Vehicles per carrying capacity per year
Source of data:	Counting
Measurement procedures (if any):	Counter should accumulate the number of trucks per carrying capacity
Monitoring frequency:	Annually
QA/QC procedures:	Number of vehicles must match with total amount of sold compost. Procedures will be checked regularly by DOE
Any comment:	

Data / Parameter:	$DT_{i,y}$
Data unit:	km
Description:	Average additional distance travelled by vehicle type *i* compared to the baseline in year *y*
Source of data:	Expert estimate
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	Assumption to be approved by DOE
Any comment:	

Data / Parameter:	$VF_{cons,i}$
Data unit:	L/km
Description:	Vehicle fuel consumption in litres per kilometre for vehicle type *i*
Source of data:	Fuel consumption record
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	
Any comment:	

Data / Parameter:	D_{fuel}
Data unit:	kg/L
Description:	Density of fuel
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	

Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	
Any comment:	Not necessary if NCV_{fuel} is demonstrated on a per liter basis

Data / Parameter:	$Q_{biomass,y}$
Data unit:	tonne/yr
Description:	Amount of waste gasified, incinerated or RDF/stabilized biomass combusted in year *y*
Source of data:	
Measurement procedures (if any):	All produced stabilized biomass will be trucked off from site. All trucks leaving site will be weighed. Possible temporary storage of stabilized biomass will be weighed as well or not taken into account for calculated carbon credits
Monitoring frequency:	
QA/QC procedures:	
Any comment:	

Data / Parameter:	EF_{N2O}
Data unit:	kgN_2O/tonne waste (dry)
Description:	Aggregate N_2O emission factor for waste incineration
Source of data:	As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	
Any comment:	

Data / Parameter:	EF_{CH4}
Data unit:	$KgCH_4$/tonne waste (dry)
Description:	Aggregate CH_4 emission factor for waste incineration
Source of data:	As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	
Any comment:	

Data / Parameter:	$S_{a,y}$
Data unit:	%
Description:	Share of the waste that degrades under anaerobic conditions in the composting plant during year *y*
Source of data:	
Measurement procedures (if any):	See $S_{total,y}$
Monitoring frequency:	Weekly
QA/QC procedures:	O_2-measurement-instrument will be subject to periodic calibration (in accordance with stipulation of instrument-supplier). Measurement itself to be done by using a standardised mobile gas detection instrument. A statistically significant sampling procedure will be set up that consists of multiple measurements throughout the different stages of the composting process according to a predetermined pattern (depths and scatter) on a weekly basis
Any comment:	Used to determine percentage of compost material that behaves anaerobically

Data / Parameter:	$S_{OD,y}$
Data unit:	Number
Description:	Number of samples with oxygen deficiency (i.e. oxygen content below 10%)
Source of data:	Oxygen measurement device
Measurement procedures (if any):	See $S_{total,y}$
Monitoring frequency:	Weekly
QA/QC procedures:	O_2-measurement-instrument will be subject to periodic calibration (in accordance with stipulation of instrument-supplier). Measurement itself to be done by using a standardised mobile gas detection instrument. A statistically significant sampling procedure will be set up that consists of multiple measurements throughout the different stages of the composting process according to a predetermined pattern (depths and scatter) on a weekly basis
Any comment:	Samples with oxygen content <10%. Weekly measurements throughout the year but accumulated once per year only

Data / Parameter:	$S_{total,y}$
Data unit:	Number
Description:	Number of samples
Source of data:	Oxygen measurement device
Measurement procedures (if any):	Statistically significant
Monitoring frequency:	Weekly

QA/QC procedures:	O_2-measurement-instrument will be subject to periodic calibration (in accordance with stipulation of instrument-supplier). Measurement itself to be done by using a standardised mobile gas detection instrument. A statistically significant sampling procedure will be set up that consists of multiple measurements throughout the different stages of the composting process according to a predetermined pattern (depths and scatter) on a weekly basis
Any comment:	Total number of samples taken per year, where $S_{total,y}$ should be chosen in a manner that ensures estimation of $S_{a,y}$ with 20% uncertainty at 95% confidence level. To determine the oxygen content during the process, project participants shall measure the oxygen content according to a predetermined sampling scheme and frequency. These measurements should be undertaken for each year of the crediting period and recorded each year

Data / Parameter:	S_{LE}
Data unit:	%
Description:	Share of samples anaerobic
Source of data:	
Measurement procedures (if any):	See $S_{LE,total}$
Monitoring frequency:	Weekly
QA/QC procedures:	O_2-measurement-instrument will be subject to periodic calibration (in accordance with stipulation of instrument-supplier). Measurement itself to be done by using a standardised mobile gas detection instrument. A statistically significant sampling procedure will be set up that consists of multiple measurements throughout the different stages of the composting process according to a predetermined pattern (depths and scatter) on a daily basis
Any comment:	Used to determine percentage of compost material that behaves anaerobically

Data / Parameter:	$S_{OD,LE}$
Data unit:	Number
Description:	Number of samples with oxygen deficiency
Source of data:	Oxygen measurement device
Measurement procedures (if any):	See $S_{LE,total}$
Monitoring frequency:	Weekly
QA/QC procedures:	O_2-measurement-instrument will be subject to periodic calibration (in accordance with stipulation of instrument-supplier). Measurement itself to be done by using a standardised mobile gas detection instrument. A statistically significant sampling procedure will be set up that consists of multiple measurements throughout the different stages of the composting process according to a predetermined pattern (depths and scatter) on a daily basis
Any comment:	Samples with oxygen content <10%. Weekly measurements throughout the year but accumulated once per year only

Data / Parameter:	$S_{LE,total}$
Data unit:	Number
Description:	Number of samples
Source of data:	Oxygen measurement device
Measurement procedures (if any):	Statistically significant
Monitoring frequency:	Weekly
QA/QC procedures:	O_2-measurement-instrument will be subject to periodic calibration (in accordance with stipulation of instrument-supplier). Measurement itself to be done by using a standardised mobile gas detection instrument. A statistically significant sampling procedure will be set up that consists of multiple measurements throughout the different stages of the composting process according to a predetermined pattern (depths and scatter) on a daily basis
Any comment:	Total number of samples taken per year, where $S_{LE,total}$ should be chosen in a manner that ensures estimation of S_{LE} with 20% uncertainty at 95% confidence level

Data / Parameter:	Degradability analysis
Data unit:	
Description:	Project proponent shall provide degradability analysis on an annual basis to demonstrate that the methane generation in the life-cycle of the SB is negligible
Source of data:	Project site
Measurement procedures (if any):	Measurement of absorption capacity for moisture of SB according to appropriate standards
Monitoring frequency:	Annually
QA/QC procedures:	
Any comment:	If the PPs produce different types of SB, they should provide this analysis for each SB type separately

Data / Parameter:	Amount of RDF/stabilized biomass used outside the project boundary
Data unit:	Tons
Description:	Project Proponents shall monitor the amount of the RDF/stabilized biomass sold for use outside of the project boundary
Source of data:	Project Site
Measurement procedures (if any):	Sale invoices of the RDF/stabilized biomass should be kept at the project site. They should contain Customer contact details, physical location of delivery, type, amount (in tons) and purpose of stabilized biomass (use as fuel or as material in furniture etc.). A list of customers and delivered SD amount should be kept at the project site
Monitoring frequency:	Weekly
QA/QC procedures:	
Any comment:	

Data / Parameter:	Temperature of the thermal treatment process
Data unit:	
Description:	The thermal treatment process (dehydration) occurs under controlled conditions (up to 300 degrees Celsius)
Source of data:	Project site
Measurement procedures (if any):	
Monitoring frequency:	
QA/QC procedures:	
Any comment:	

Data / Parameter:	$A_{j,x}$
Data unit:	tonnes/yr
Description:	Amount of organic waste type j prevented from disposal in the landfill in the year *x* (tonnes/year)
Source of data:	Project participants
Measurement procedures (if any):	Weighbridge
Monitoring frequency:	Annually
QA/QC procedures:	Weighbridge will be subject to periodic calibration (in accordance with stipulation of the weighbridge supplier)
Any comment:	

Data / Parameter:	$A_{ci,x}$
Data unit:	tonnes/yr
Description:	Amount of residual waste type 'ci' from anaerobic digestion, gasifier or processing/combustion of RDF and stabilized biomass
Source of data:	Project participants
Measurement procedures (if any):	Weighbridge
Monitoring frequency:	Annually
QA/QC procedures:	Weighbridge will be subject to periodic calibration (in accordance with stipulation of the weighbridge supplier)
Any comment:	

Data / Parameter:	R_n
Data unit:	tonnes/yr
Description:	Weight of RDF/stabilized biomass sold offsite for which no sale invoices can be provided
Source of data:	Project participants
Measurement procedures (if any):	Weighbridge
Monitoring frequency:	Annually

QA/QC procedures:	Weighbridge will be subject to periodic calibration (in accordance with stipulation of the weighbridge supplier)
Any comment:	

Data / Parameter:	R_t
Data unit:	tonnes/yr
Description:	Total weight of RDF/stabilized biomass produced (t/yr)
Source of data:	Project participants
Measurement procedures (if any):	Weighbridge
Monitoring frequency:	Annually
QA/QC procedures:	Weighbridge will be subject to periodic calibration (in accordance with stipulation of the weighbridge supplier)
Any comment:	

Data / Parameter:	$A_{residual}$
Data unit:	tonnes/yr
Description:	The amount of the residual waste from the incinerator
Source of data:	Project participants
Measurement procedures (if any):	Weighbridge
Monitoring frequency:	Aggregated at least annually
QA/QC procedures:	
Any comment:	Weighbridge will be subject to periodic calibration (in accordance with stipulation of the weighbridge supplier)

Data / Parameter:	$FC_{residual}$
Data unit:	%
Description:	Fraction of residual carbon in the residual waste of MSW incinerator
Source of data:	Sample measurements by project participants
Measurement procedures (if any):	
Monitoring frequency:	The size and frequency of sampling should be statistically significant with a maximum uncertainty range of 20% at a 95% confidence level. As a minimum, sampling should be undertaken four times per year
QA/QC procedures:	
Any comment:	

Data / Parameter:	$Q_{COD,y}$
Data unit:	m^3/yr
Description:	Amount of waste waster treated anaerobically or released untreated from the project activity in year *y*
Source of data:	Measured value by flow meter
Measurement procedures (if any):	-
Monitoring frequency:	Monthly aggregated annually
QA/QC procedures:	The monitoring instruments will be subject to regular maintenance and testing to ensure accuracy
Any comment:	If the wastewater is treated aerobically, emissions are assumed to be zero, and hence this parameter does not need to be monitored

Data / Parameter:	$P_{COD,y}$
Data unit:	$tCOD/m^3$
Description:	Chemical Oxygen Demand (COD) of wastewaster
Source of data:	Measured value by purity meter
Measurement procedures (if any):	-
Monitoring frequency:	Monthly and averaged annually
QA/QC procedures:	The monitoring instruments will be subject to regular maintenance and testing to ensure accuracy
Any comment:	If the wastewater is treated aerobically, emissions are assumed to be zero, and hence this parameter does not need to be monitored

Data / Parameter:	$f_{c/g/d/r/i}$
Data unit:	%
Description:	Fraction of waste diverted, from the landfill to all project activities: composting/gasification/anaerobic digestion/RDF/stabilized biomass/ incineration
Source of data:	Plant records
Measurement procedures (if any):	
Monitoring frequency:	Monthly
QA/QC procedures:	
Any comment:	

Data / Parameter:	Q_y
Data unit:	TJ
Description:	Net quantity of thermal energy supplied by the project activity in year *y*
Source of data:	Steam meter
Measurement procedures (if any):	-In case of steam meter: The enthalpy of steam and feed water will be determined at measured temperature and pressure and the enthalpy difference will be multiplied with quantity measured by steam meter. -In case of hot air: the temperature, pressure and mass flow rate will be measured.
Monitoring frequency:	Monthly
QA/QC procedures:	In case of monitoring of steam, it will be calibrated for pressure and temperature of steam at regular intervals. The meter shall be subject to regular maintenance and testing to ensure accuracy.
Any comment:	The dedicated quantity of thermal energy generated for heat supply or cogeneration by the project activity if included

Data / Parameter:	Amount of compost produced
Data unit:	Tons
Description:	Project Proponents shall monitor the amount of the compost produced from the composting treatment process
Source of data:	Project site
Measurement procedures (if any):	Sales invoices of the compost should be kept at the project site. They should contain customer contact details, physical location of delivery, type, amount (in tons) and the use of compost. A list of customers and delivered SD amount should be kept at the project site
Monitoring frequency:	Weekly
QA/QC procedures:	
Any comment:	

Data / Parameter:	-
Data unit:	MJ
Description:	Energy generated by auxiliary fossil fuel added in the incinerator
Source of data:	Project site
Measurement procedures (if any):	This parameter will be estimated multiplying the amount of auxiliary fossil fuel added in the incinerator to the net calorific value of this auxiliary fossil fuel
Monitoring frequency:	Annually
QA/QC procedures:	
Any comment:	This parameter will be used to assess that the fraction of energy generated by fossil fuel is no more than 50% of the total energy generated in the incinerator. Energy generated by fossil fuel $< 0.50 \times (Qy + EG_{d,y})$

Data / Parameter:	$F_{co\text{-}firing,y}$
Data unit:	mass or volume units of fossil fuel consumption
Description:	Fuel consumption on-site for thermal energy generation/ electricity generation during year *y* of the crediting period
Source of data:	Purchase invoices and/or metering
Measurement procedures (if any):	
Monitoring frequency:	Annually
QA/QC procedures:	The amount of fuel will be derived from the paid fuel invoices (administrative obligation)
Any comment:	This parameter includes the fossil fuels that are co-fired with stabilized biomass for thermal energy generation/ electricity generation

Data / Parameter:	$NCV_{co\text{-}firing,y}$
Data unit:	MJ/mass or volume units of fossil fuel
Description:	Net calorific value of fossil fuel used for thermal energy generation/electricity generation
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	
Any comment:	

Data / Parameter:	$EF_{co\text{-}firing}$
Data unit:	tCO_2/MJ
Description:	Emission factor of the fossil fuel used for thermal energy generation/electricity generation
Source of data:	The source of data should be the following, in order of preference: project specific data, country specific data or IPCC default values. As per guidance from the Board, IPCC default values should be used only when country or project specific data are not available or difficult to obtain
Measurement procedures (if any):	
Monitoring frequency:	Annually or *ex ante*
QA/QC procedures:	
Any comment:	

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History of the document

Version	Date	Nature of revision
12	EB 55, Annex 4 30 July 2010	• To clarify that project activities that process and upgrade biogas from anaerobic digestion to the quality of natural gas and then distribute it as energy via natural gas distribution grid can use the approved methodology AM0053 in conjunction with this methodology; • To provide separate procedures to estimate emissions from thermal energy generation/electricity generation during co-firing fossil fuel with biomass to allow for cases when the fossil fuel used in the boiler is different than that used for other purposes on-site; • To provide a conservative approach to estimate emissions from residual waste from different treatment processes when disposed of in landfills; • To correct equation 6, so that the Global Warming Potential of methane (GWP_{CH4}) is not taken into account twice.
11	EB 44, Annex 7 28 November 2008	• Addition of a circulating fluidized bed incinerator as a possible technology in the project activity; • Inclusion of an applicability condition to limit the use of auxiliary fossil fuels in the incinerator; • Clarification on the measurement procedure for fossil-based carbon in the waste; • Addition of procedure to estimate leakage emissions from the residual waste from MSW incineration.
10.1	EB 41, Paragraph 26(g) 02 August 2008	The title of the "Tool to determine methane emissions avoided from dumping waste at a solid waste disposal site" changes to "Tool to determine methane emissions avoided from disposal of waste at a solid waste disposal site".
10	EB 35, Paragraph 24 19 October 2007	To amend the methodology replacing the reference to ACM0002 by a reference to the "Tool to calculate the emission factor for an electricity system".
09	EB 33, Annex 8 27 July 2007	To correct an oversight where in the methodology avoidance of methane from anaerobic decay of biomass is credited even for that fraction of biomass, which is identified as not being surplus and thus would not have been dumped and thereby not causing methane emissions.
08	EB 32, Annex 7 22 June 2007	To clarify that the methodology is applicable to project activities: where output of composting activity is disposed of in landfill; and where refuse derived fuel is used for either generation of heat or co-generating energy.
07	EB 31, Annex 5 04 May 2007	To incorporate the proposed new methodology NM0174-rev (MSW Incineration Project in Guanzhuang, Tianjin City, China) expanding its applicability to projects activities that use incineration of municipal solid waste to generate energy.
06	EB 29, Annex 4 16 February 2007	• To incorporate the proposed new methodology NM0178 (Aerobic thermal treatment of municipal solid waste (MSW) without incineration in Parobé); • To revise the procedure for estimating methane emissions from anaerobic pockets of waste being treated through composting.
05	EB 27, Annex 7 1 November 2006	Expand the applicability of the methodology to project activities that use a mechanical process to produce refuse-derived fuel (RDF) for power generation from municipal solid waste.
04	EB 26, Annex 9 29 September 2006	Expand the applicability of the methodology to project activities that: • Use anaerobic digestion to treat municipal solid waste, which in absence of the project activity would have been disposed in a landfill; • Are implemented in a country where mandatory regulation exist to treat the biodegradable part of the municipal solid waste before disposing the waste in a landfill, but the regulation is not implemented.

03	EB 23, Annex 6 24 February 2006	• Allow the use of procedure defined in AMS I.D for estimating electricity emission factor if the electricity consumed/supplied meets the eligibility criteria of small scale; • Expand the applicability of the methodology to alternative treatment process other than composting.
02	EB 22, Annex 4 25 November 2005	The title was amended in order to clarify that the methodology also applies to organic waste composting that occurs outside the landfill sites.
01	EB 21, Annex 15 30 September 2005	Initial adoption.
Decision Class: Regulatory **Document Type**: Standard **Business Function**: Methodology		

Exhibit 4

Is It Better To Burn or Bury Waste for Clean Electricity Generation?

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The use of municipal solid waste (MSW) to generate electricity through landfill-gas-to-energy (LFGTE) and waste-to-energy (WTE) projects represents roughly 14% of U.S. nonhydro renewable electricity generation. Although various aspects of LFGTE and WTE have been analyzed in the literature, this paper is the first to present a comprehensive set of life-cycle emission factors per unit of electricity generated for these energy recovery options. In addition, sensitivity analysis is conducted on key inputs (e.g., efficiency of the WTE plant, landfill gas management schedules, oxidation rate, and waste composition) to quantify the variability in the resultant life-cycle emissions estimates. While methane from landfills results from the anaerobic breakdown of biogenic materials, the energy derived from WTE results from the combustion of both biogenic and fossil materials. The greenhouse gas emissions for WTE ranges from 0.4 to 1.5 $MTCO_2e$/MWh, whereas the most agressive LFGTE scenerio results in 2.3 $MTCO_2e$/MWh. WTE also produces lower NO_x emissions than LFGTE, whereas SO_x emissions depend on the specific configurations of WTE and LFGTE.

Introduction

In response to increasing public concern over air pollution and climate change, the use of renewable energy for electricity generation has grown steadily over the past few decades. Between 2002 and 2006, U.S. renewable electricity generation—as a percent of total generation—grew an average of 5% annually (*1*), while total electricity supply grew by only 1% on average (*2*). Support mechanisms contributing to the growth of renewables in the United States include corporate partnership programs, investment tax credits, renewable portfolio standards, and green power markets. These mechanisms provide electric utilities, investment firms, corporations, governments, and private citizens with a variety of ways to support renewable energy development. With several competing renewable alternatives, investment and purchasing decisions should be informed, at least in part, by rigorous life-cycle assessment (LCA).

In 2005, a total of 245 million tons of MSW was generated in the United States, with 166 million tons discarded to landfills (*3*). Despite the increase in recycling and composting rates, the quantity of waste disposed to landfills is still significant and expected to increase. How to best manage the discarded portion of the waste remains an important consideration, particularly given the electricity generation options. Although less prominent than solar and wind, the use of municipal solid waste (MSW) to generate electricity represents roughly 14% of U.S. nonhydro renewable electricity generation (*1*). In this paper we compare two options for generating electricity from MSW. One method, referred to as landfill-gas-to-energy (LFGTE), involves the collection of landfill gas (LFG) (50% CH_4 and 50% CO_2), which is generated through the anaerobic decomposition of MSW in landfills. The collected LFG is then combusted in an engine or a turbine to generate electricity. A second method, referred to as waste-to-energy (WTE) involves the direct combustion of MSW, where the resultant steam is used to run a turbine and electric generator.

Clean Air Act (CAA) regulations require capture and control of LFG from large landfills by installing a gas collection system within 5 years of waste placement (*4*). The gas collection system is expanded to newer areas of the landfill as more waste is buried. Not all LFG is collected due to delays in gas collection from initial waste placement and leaks in the header pipes, extraction wells, and cover material. Collected gas can be either flared or utilized for energy recovery. As of 2005, there were 427 landfills out of 1654 municipal landfills in the United States with LFGTE projects for a total capacity of 1260 MW. It is difficult to quantify emissions with a high degree of certainty since emissions result from biological processes that can be difficult to predict, occur over multiple decades, and are distributed over a relatively large area covered by the landfill.

CAA regulations require that all WTE facilities have the latest in air pollution control equipment (*5*). Performance data including annual stack tests and continuous emission monitoring are available for all 87 WTE plants operating in 25 states. Since the early development of this technology, there have been major improvements in stack gas emissions controls for both criteria and metal emissions. The performance data indicate that actual emissions are less than regulatory requirements. Mass burn is the most common and established technology in use, though various MSW combustion technologies are described in ref 6. All WTE facilities in the United States recover heat from the combustion process to run a steam turbine and electricity generator.

Policy-makers appear hesitant to support new WTE through new incentives and regulation. Of the 30 states that have state-wide renewable portfolio standards, all include landfill gas as an eligible resource, but only 19 include waste-to-energy (*7*). While subjective judgments almost certainly play a role in the preference for LFGTE over WTE, there is a legitimate concern about the renewability of waste-to-energy. While the production of methane in landfills is the result of the anaerobic breakdown of biogenic materials, a significant fraction of the energy derived from WTE results from combusting fossil-fuel-derived materials, such as plastics. Countering this effect, however, is significant methane leakage—ranging from 60% to 85%—from landfills (*8*). Since methane has a global warming potential of 21 times that of CO_2, the CO_2e emissions from LFGTE may be larger than those from WTE despite the difference in biogenic composition.

Although WTE and LFGTE are widely deployed and analyzed in the literature (*9–13*), side-by-side comparison of the life-cycle inventory (LCI) emission estimates on a mass

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per unit energy basis is unavailable. LCI-based methods have been used to evaluate and compare solid waste management (SWM) unit operations and systems holistically to quantify either the environmental impacts or energy use associated with SWM options in the broad context of MSW management (*14–16*).

The purpose of this paper is to present a comprehensive set of life-cycle emission factors—per unit of electricity generated—for LFGTE and WTE. In addition, these emission factors are referenced to baseline scenarios without energy recovery to enable comparison of the emissions of LFGTE and WTE to those of other energy sources. While the methodology presented here is applicable to any country, this analysis is based on U.S. waste composition, handling, and disposal, with which the authors are most familiar. In addition, parametric sensitivity analysis is applied to key input parameters to draw robust conclusions regarding the emissions from LFGTE and WTE. The resultant emission factors provide critical data that can inform the development of renewable energy policies as well as purchasing and investment decisions for renewable energy projects in the prevailing marketplace.

Modeling Framework

The LFGTE and WTE emission factors are based on the composition and quantity of MSW discarded in the United States in 2005 (Table S1 of Supporting Information (SI)). We excluded the estimated quantity and composition of recycled and composted waste.

The emission factors are generated using the life-cycle-based process models for WTE (*17*) and LF/LFGTE (*18*) embedded in the municipal solid waste decision support tool (MSW-DST). The MSW-DST was developed through a competed cooperative agreement between EPA's Office of Research and Development and RTI International (*19–22*). The research team included North Carolina State University, which had a major role in the development of the LCI database, process, and cost models as well as the prototype MSW-DST. While a summary is provided here, Table S2 (SI) provides a comprehensive set of references for those interested in particular model details. The MSW-DST includes a number of process models that represent the operation of each SWM unit and all associated processes for collection, sorting, processing, transport, and disposal of waste. In addition, there are process models to account for the emissions associated with the production and consumption of gasoline and electricity. The objective of each process model is to relate the quantity and composition of waste entering a process to the cost and LCI of emissions for that process. The LCI emissions are calculated on the basis of a combination of default LCI data and user-input data to enable the user to model a site-specific system. For example, in the landfill process model, one key exogenous input is the efficiency of the LFG collection system. The functional unit in each process model is 1 ton of MSW set out for collection. The MSW includes the nonhazardous solid waste generated in residential, commercial, institutional, and industrial sectors (*3*).

Each process model can track 32 life-cycle parameters, including energy consumption, CO_2, CO, NO_x, SO_x, total greenhouse gases (CO_2e), particulate matter (PM), CH_4, water pollutants, and solid wastes. CO_2 emissions are represented in two forms: fossil and biogenic. CO_2 released from anthropogenic activities such as burning fossil fuels or fossil-fuel-derived products (e.g., plastics) for electricity generation and transportation are categorized as CO_2-fossil. Likewise, CO_2 released during natural processes such as the decay of paper in landfills is categorized as CO_2-biogenic.

The management of MSW will always result in additional emissions due to collection, transportation, and separation of waste. However, for this analysis, the configuration of the SWM system up through the delivery of the waste to either a landfill or WTE facility is assumed to be same.

TABLE 1. Inputs to the Landfill Process Model

	LFG collection system efficiency [a] (%)	oxidation rate (%)
during venting	0	15
during first year of gas collection	50	15
during second year of gas collection	70	15
during third year and on of gas collection	80	15

[a] We assumed efficiency of the collection system based on the year of the operation and the ranges stated in U.S. EPA's AP-42 (*8*).

Electricity Grids. While LFGTE and WTE provide emissions reductions relative to landfill scenarios without energy recovery, the generation of electricity from these sources also displaces conventional generating units on the electricity grid. The process models in MSW-DST can calculate total electricity generated and apply an offset analysis on the grid mix of fuels specific to each of the North American Electric Reliability Council (NERC) regions, an average national grid mix, or a user-defined grid mix. Because our focus is on the emissions differences between WTE and LFGTE technologies, the emissions factors reported here exclude the displaced grid emissions.

For reference purposes, emission factors for conventional electricity-generating technologies are reported along with the emission factors for WTE and LFGTE (*23*). These emission factors on a per megawatt hour basis include both the operating emissions from power plants with postcombustion air pollution control equipment and precombustion emissions due to extraction, processing, and transportation of fuel. The background LCI data are collected on a unit mass of fuel (*23*); when converted on a per unit of electricity generated basis, the magnitude of resultant emissions depends on the efficiency of the power plant. A sensitivity analysis was conducted on plant efficiencies to provide ranges for emission factors.

Estimating Emission Factors for Landfill Gas-to-Energy. The total LCI emissions from landfills are the summation of the emissions resulting from (1) the site preparation, operation, and postclosure operation of a landfill, (2) the decay of the waste under anaerobic conditions, (3) the equipment utilized during landfill operations and landfill gas management operations, (4) the production of diesel required to operate the vehicles at the site, and (5) the treatment of leachate (*18*). The production of LFG was calculated using a first-order decay equation for a given time horizon of 100 years and the empirical methane yield from each individual waste component (*18, 24*). Other model inputs include the quantity and the composition of waste disposed (Table S1, SI), LFG collection efficiency (Table 1), annual LFG management schedule (Figure 1), oxidation rate (Table 1), emission factors for combustion byproduct from LFG control devices (Table S3, SI), and emission factors for equipment used on site during the site preparation and operation of a landfill. While there are hundreds of inputs to the process models, we have modified and conducted sensitivity analysis on the input parameters that will affect the emission factors most significantly.

The emission factors are calculated under the following scenario assumptions: (1) A regional landfill subject to CAA is considered. (2) A single cell in the regional landfill is modeled. (3) Waste is initially placed in the new cell in year 0. (4) The landfill already has an LFG collection network in place. (5) An internal combustion engine (ICE) is utilized to generate electricity. (6) The offline time that is required for

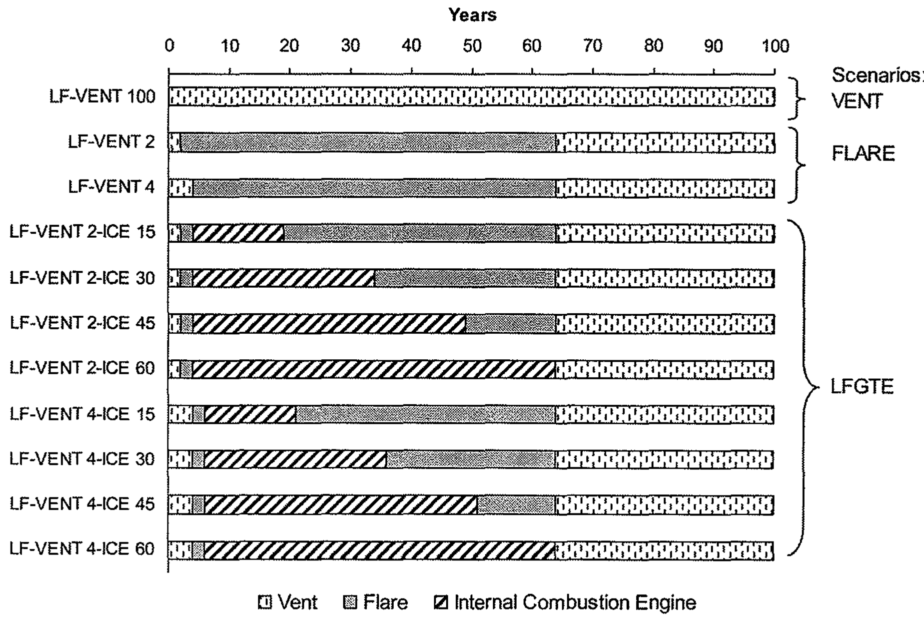

FIGURE 1. Annual landfill gas management schedule assumed for alternative scenarios.

the routine maintenance of the ICE is not considered. (7) The LFG control devices are assumed to have a lifetime of 15 years. (8) The LFG will be collected and controlled until year 65. This assumption is based on a typical landfill with an average operating lifetime of 20 years in which LFG production decreases significantly after about 60 years from initial waste placement. This is based on the use of a first-order decay equation utilizing empirical data from about 50 U.S. LFG collection systems.

The timing of LFG-related operations has significant variation and uncertainty that will influence the total emissions from landfills as well as the emission factors per unit of electricity generated. To capture these uncertainties and variation, several different management schemes were tested. Figure 1 presents the different cases considered for LFGTE projects. Each case differs according to the management timeline of the LFG. For instance, LF-VENT 2-ICE 15 corresponds to no controls on LFG for the first two years, after which the LFG is collected and flared in the third and fourth years. From year 5 until year 19, for a period of 15 years, the LFG is processed through an ICE to generate electricity, after which the collected gas is flared until year 65. Finally from year 65 on, the LFG is released to the atmosphere without controls.

To quantify the emissions benefit from LFGTE and WTE, landfill emissions occurring in the absence of an energy recovery unit can serve as a useful comparison. Thus, three baseline scenarios without electricity generation were defined for comparison to the energy recovery scenarios: LF-VENT 100 (LFG is uncontrolled for the entire lifetime of the LF), LF-VENT 2 (LFG is uncontrolled for the first two years, and then the LFG is collected and flared until year 65), LF-VENT 4 (LFG is uncontrolled for the first four years, and then the LFG is collected and flared until year 65). Since emissions are normalized by the amount of electricity generated (MW h) to obtain the emission rates, an estimate of hypothetical electricity generation for the baseline scenarios must be defined. The average electricity generation from a subset of the energy recovery scenarios is used to calculate the baseline emission rates. For example, emission factors [g/(MW h)] for LF-VENT 2 are based on the average of electricity generated in LF-VENT 2-ICE 15, LF-VENT 2-ICE 30, LF-VENT 2-ICE 45, and LF-VENT 2-ICE 60. Additional sensitivity analysis was conducted on oxidation rates where scenarios were tested for a range of 10−35%.

Estimating Emission Factors for Waste-to-Energy. The total LCI emissions are the summation of the emissions associated with (1) the combustion of waste (i.e., the stack gas (accounting for controls)), (2) the production and use of limestone in the control technologies (i.e., scrubbers), and (3) the disposal of ash in a landfill (*17*).

Emissions associated with the manufacture of equipment such as turbines and boilers for the WTE facility are found to be insignificant (<5% of the overall LCI burdens) and, as a result, were excluded from this analysis (*25*). In addition, WTE facilities have the capability to recover ferrous material from the incoming waste stream and also from bottom ash with up to a 90% recovery rate. The recovered metal displaces the virgin ferrous material used in the manufacturing of steel. The emission offsets from this activity could be significant depending on the amount of ferrous material recovered. Total LCI emissions for WTE were presented without the ferrous offsets; however, sensitivity analysis was conducted to investigate the significance.

In the United States, federal regulations set limits on the maximum allowable concentration of criteria pollutants and some metals from MSW combustors (*5*). The LCI model calculates the controlled stack emissions using either the average concentration values at current WTE facilities based on field data or mass emission limits based on regulatory requirements as upper bound constraints. Two sets of concentration values (Table S4, SI) are used in calculations to report two sets of emission factors for WTE (i.e., WTE-Reg and WTE-Avg). The emission factors for WTE-Reg were based on the regulatory concentration limits (*5*), whereas the emission factors for WTE-Avg were based on the average concentrations at current WTE facilities.

The CO_2 emissions were calculated using basic carbon stoichiometry given the quantity, moisture, and ultimate analysis of individual waste items in the waste stream. The LCI model outputs the total megawatt hour of electricity production and emissions that are generated per unit mass of each waste item. The amount of electricity output is a function of the quantity, energy, and moisture content of the individual waste items in the stream (Table S1, Supporting Information), and the system efficiency. A lifetime of 20 years and a system efficiency of 19% [18000 Btu/(kW h)] were assumed for the WTE scenarios. For each pollutant, the following equation was computed:

$$LCI\_WTE_i = \sum_j \{(LCI\_Stack_{ij} + LCI\_Limestone_{ij} + LCI\_Ash_{ij}) \times Mass_j\}/Elec \quad \text{for all } i \quad (1)$$

where LCI_WTE_i is the LCI emission factor for pollutant i [g/(MW h)], LCI_Stack_{ij} is the controlled stack gas emissions for pollutant i (g/ton of waste item j), $LCI\_Limestone_{ij}$ is the allocated emissions of pollutant i from the production and use of limestone in the scrubbers (g/ton of waste item j), LCI_Ash_{ij} is the allocated emissions of pollutant i from the disposal of ash (g/ton of waste item j), $Mass_j$ is the amount of each waste item j processed in the facility (ton), and Elec is the total electricity generated from MSW processed in the facility (MW h). In addition, the sensitivity of emission factors to the system efficiency, the fossil and biogenic fractions of MSW, and the remanufacturing offsets from steel recovery was quantified.

Results and Discussion

The LCI emissions resulting from the generation of 1 MW h of electricity through LFGTE and WTE as well as coal, natural gas, oil, and nuclear power (for comparative purposes) were calculated. The sensitivity of emission factors to various inputs was analyzed and is reported. Figures 2–4 summarize the emission factors for total CO_2e, SO_x, and NO_x, respectively.

Landfills are a major source of CH_4 emissions, whereas WTE, coal, natural gas, and oil are major sources of CO_2-fossil emissions (Table S5, SI). The magnitude of CH_4 emissions strongly depends on when the LFG collection system is installed and how long the ICE is used. For example, LF-VENT 2-ICE 60 has the least methane emissions among LFGTE alternatives because the ICE is operated the longest (Table S5, SI). CO_2e emissions from landfills were significantly higher than the emissions for other alternatives because of the relatively high methane emissions (Figure 2, Table S5).

The use of LFG control during operation, closure, and postclosure of the landfill as well as the treatment of leachate contributes to the SO_x emissions from landfills. SO_x emissions from WTE facilities occur during the combustion process and are controlled via wet or dry scrubbers. Overall, the SO_x emissions resulting from the LFGTE and WTE alternatives are approximately 10 times lower than the SO_x emissions resulting from coal- and oil-fired power plants with flue gas controls (Figure 3). The SO_x emissions for WTE ranged from 140 to 730 g/(MW h), and for LFGTE they ranged from 430 to 900 g/(MW h) (Table 2, Table S5). In a coal-fired power plant, average SO_x emissions were 6900 g/(MW h) (Table S6 and S7, SI). Another important observation is that the majority of the SO_x emissions from natural gas are attributed to processing of natural gas rather than the combustion of the natural gas for electricity-generating purposes.

The NO_x emissions for WTE alternatives ranged from 810 to 1800 g/(MW h), and for LFGTE they ranged from 2100 to 3000 g/(MW h) (Figure 4, Table 2, Table S5). In a coal-fired power plant, average NO_x emissions are 3700 g/(MW h) (Tables S6 and S7, Supporting Information). The emission factors for other criteria pollutants were also calculated. Besides CO and HCl emissions, the emission factors for all LFGTE and WTE cases are lower than those for the coal-fired generators (Tables S5–S8, SI).

While we have provided a detailed, side-by-side comparison of life-cycle emissions from LFGTE and WTE, there is an important remaining question about scale: How big an impact can energy recovery from MSW make if all of the discarded MSW (166 million tons/year) is utilized? Hypothetically, if 166 million tons of MSW is discarded in regional landfills, energy recovery on average of ~10 TW h or ~65 (kW h)/ton of MSW of electricity can be generated, whereas a WTE facility can generate on average ~100 TW h or ~600 (kW h)/ton of MSW of electricity with the same amount of MSW (Table 3). WTE can generate an order of magnitude more electricity than LFGTE given the same amount of waste. LFGTE projects would result in significantly lower electricity generation because only the biodegradable portion of the MSW contributes to LFG generation, and there are significant inefficiencies in the gas collection system that affect the quantity and quality of the LFG.

Moreover, if all MSW (excluding the recycled and composted portion) is utilized for electricity generation, the WTE alternative could have a generation capacity of 14000 MW, which could potentially replace ~4.5% of the 313000 MW of current coal-fired generation capacity (*26*).

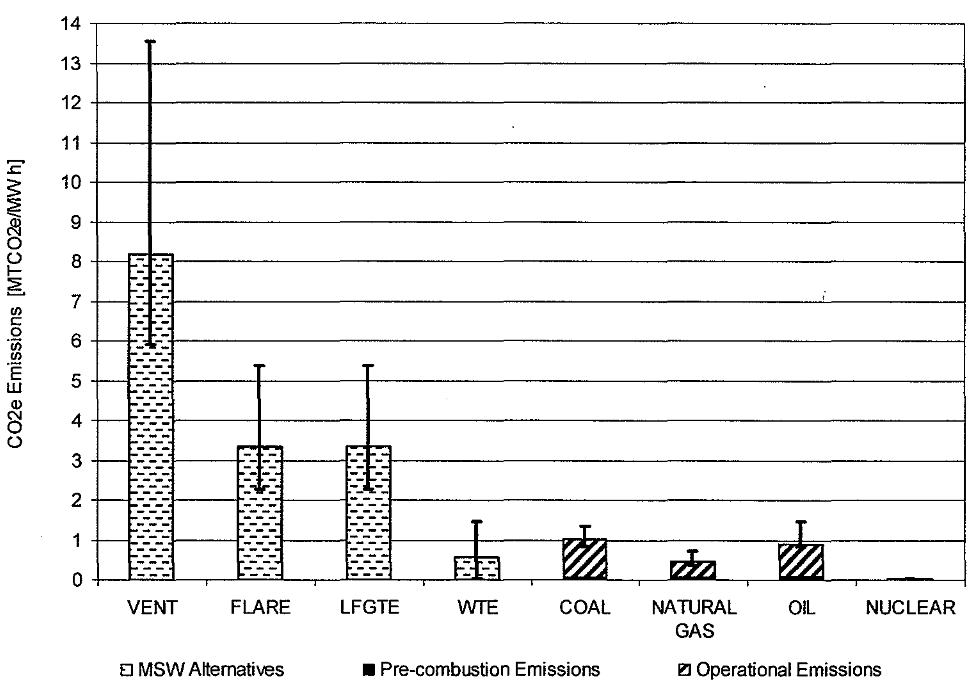

FIGURE 2. Comparison of carbon dioxide equivalents for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5–S8, Supporting Information, include the full data set).

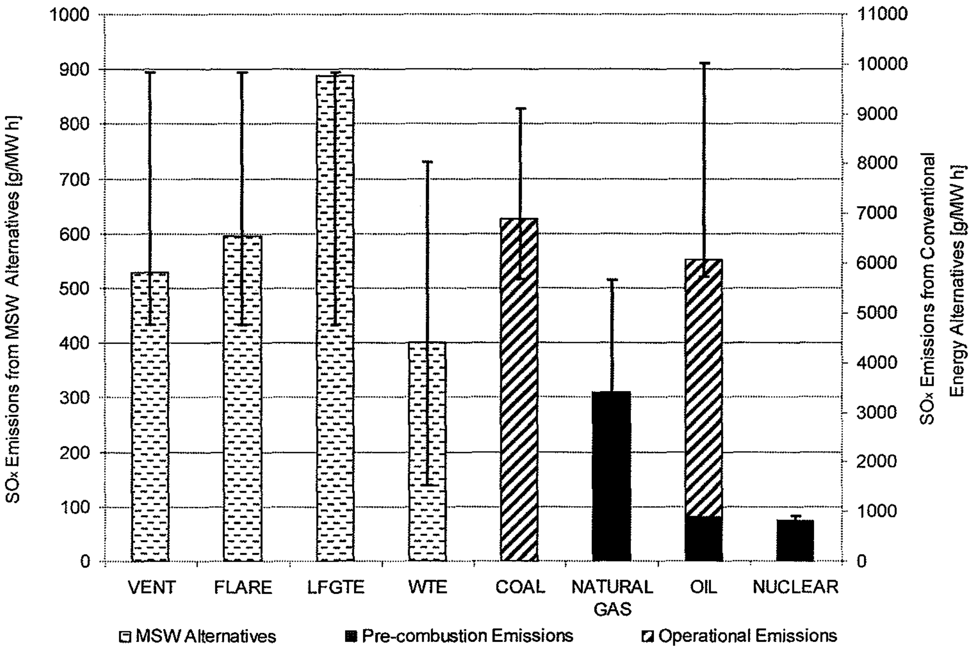

FIGURE 3. Comparison of sulfur oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5–S8, Supporting Information, include the full data set).

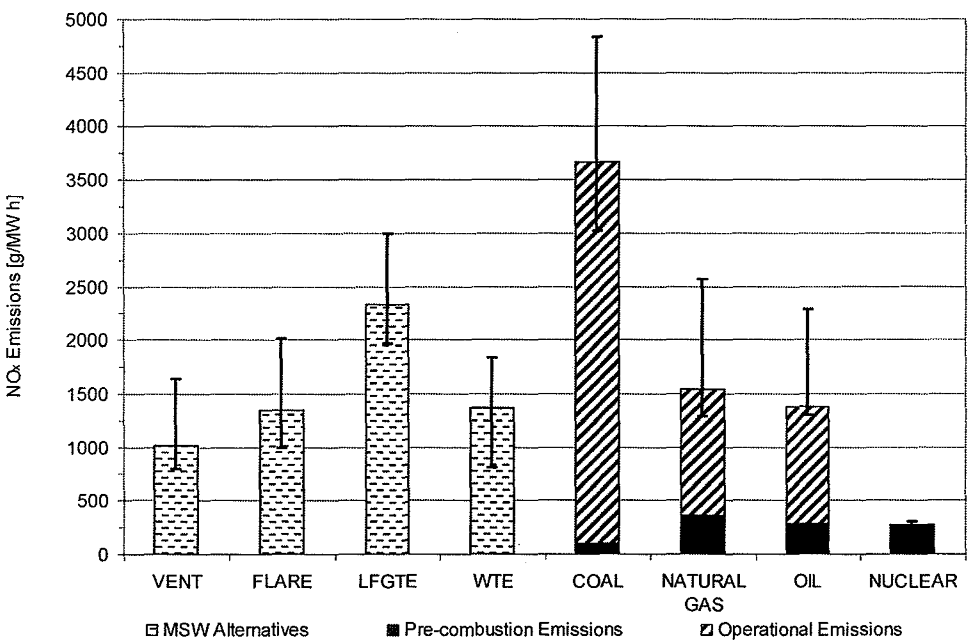

FIGURE 4. Comparison of nitrogen oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5–S8, Supporting Information, include the full data set).

A significant portion of this capacity could be achieved through centralized facilities where waste is transported from greater distances. The transportation of waste could result in additional environmental burdens, and there are clearly limitations in accessing all discarded MSW in the nation. Wanichpongpan studied the LFGTE option for Thailand and found that large centralized landfills with energy recovery performed much better in terms of cost and GHG emissions than small, localized landfills despite the increased burdens associated with transportation (*13*). To quantify these burdens for the United States, emission factors were also calculated for long hauling of the waste via freight or rail. Table S9 (SI) summarizes the emission factors for transporting 1 ton of MSW to a facility by heavy-duty trucks and rail.

Sensitivity analysis was also conducted on key inputs. With incremental improvements, WTE facilities could achieve efficiencies that are closer to those of conventional power plants. Thus, the system efficiency was varied from 15% to 30%, and Table 2 summarizes the resulting LCI emissions. The variation in efficiencies results in a range of 470–930 kW h of electricity/ton of MSW, while with the default heat rate, only 600 (kW h)/ton of MSW can be generated. The efficiency also affects the emission factors; for example, CO_2-fossil emissions vary from 0.36 to 0.71 Mg/(MW h).

The emission savings associated with ferrous recovery decreased the CO_2e emissions of the WTE-Reg case from 0.56 to 0.49 $MTCO_2e$/(MW h). Significant reductions were observed for CO and PM emissions (Table 2).

TABLE 2. Sensitivity of Emission Factors for WTE to Plant Efficiency, Waste Composition, and Remanufacturing Benefits of Steel Recovery

			Sensitivity on				
	baseline factors		system efficiency	waste composition		steel recovery	
	Input Parameters Varied[a]						
heat rate [Btu/(kW h)]	18000	18000	*[11000, 23000]*	18000	18000	18000	18000
efficiency (%)	19	19	*[15, 30]*	19	19	19	19
composition	default	default	default	*all biogenic*	*all fossil*	default	default
stack gas limits	reg	avg	*reg/avg*	reg	reg	*reg*	*avg*
steel recovery	excludes	excludes	excludes	excludes	excludes	*includes*	*includes*
	Results: Criteria Pollutants						
CO [g/(MW h)]	790	790	[500,1000]	740	880	−110	−110
NO_x [g/(MW h)]	1300	1500	[810, 1800]	1200	1400	1200	1400
SO_x [g/(MW h)]	578	221	[140, 730]	550	620	450	90
PM [g/(MW h)]	181	60	[38, 230]	180	190	−190	−310
	Results: Greenhouse Gases						
CO_2-biogenic [Mg/(MW h)]	0.91	0.91	[0.58, 1.2]	1.5	0.03	0.91	0.91
CO_2-fossil [Mg/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.5	0.49	0.49
CH_4 [Mg/(MW h)]	1.3E−05	1.3E−05	[8.1E−06, 1.6E−05]	1.6E−05	7.9E−06	−5.0E−05	−5.0E−05
CO_2e [$MTCO_2e$/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.45	0.49	0.49
	Results: Electricity Generation						
TW h [b]	98	98	[78, 160]	61	37	98	98
(kW h)/ton	590	590	[470, 930]	470	970	590	590
GW [c]	12	12	[9.7, 20]	7.6	4.7	12	12

[a] For each sensitivity analysis scenario, the input parameters in italics were modified and resultant emission factors were calculated and are reported. [b] The values represent the TWh of electricity that could be generated from all MSW disposed into landfills. [c] 1 TWh/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

TABLE 3. Comparison of Total Power Generated

	total electricity generated from 166 million tons of MSW, TW h	total power [a], GW	electricity generated from 1 ton of MSW, (kW h)/ton
waste-to-energy	78−160	9.7−19	470−930
landfill-gas-to-energy	7−14	0.85−1.8	41−84

[a] 1 TW h/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

The composition of MSW also has an effect on the emission factors. One of the controversial aspects of WTE is the fossil-based content of MSW, which contributes to the combustion emissions. The average composition of MSW as discarded by weight was calculated to be 77% biogenic- and 23% fossil-based (Table S1, SI). The sensitivity of emission factors to the biogenic- vs fossil-based waste fraction was also determined. Two compositions (one with 100% biogenic-based waste and another with 100% fossil-based waste) were used to generate the emission factors (Table 2). The CO_2e emissions from WTE increased from 0.56 $MTCO_2e$/(MW h) (WTE-Reg) to 1.5 $MTCO_2e$/(MW h) when the 100% fossil-based composition was used (Table 2, Figure 2). However, the CO_2e emissions from WTE based on 100% fossil-based waste were still lower than the most aggressive LFGTE scenario (i.e., LF-VENT 2-ICE 60) whose CO_2e emissions were 2.3 $MTCO_2e$/(MW h).

The landfill emission factors include the decay of MSW over 100 years, whereas emissions from WTE and conventional electricity-generating technologies are instantaneous. The operation and decomposition of waste in landfills continue even beyond the monitoring phases for an indefinite period of time. Reliably quantifying the landfill gas collection efficiency is difficult due to the ever-changing nature of landfills, number of decades that emissions are generated, and changes over time in landfill design and operation including waste quantity and composition. Landfills are an area source, which makes emissions more difficult to monitor. In a recent release of updated emission factors for landfill gas emissions, data were available for less than 5% of active municipal landfills (*27*). Across the United States, there are major differences in how landfills are designed and operated, which further complicates the development of reliable emission factors. This is why a range of alternative scenarios are evaluated with plausible yet optimistic assumptions for LFG control. For WTE facilities, there is less variability in the design and operation. In addition, the U.S. EPA has data for all the operating WTE facilities as a result of CAA requirements for annual stack testing of pollutants of concern, including dioxin/furan, Cd, Pb, Hg, PM, and HCl. In addition, data are available for SO_2, NO_x, and CO from continuous emissions monitoring. As a result, the quality and availability of data for WTE versus LFGTE results in a greater degree of certainty for estimating emission factors for WTE facilities.

The methane potential of biogenic waste components such as paper, food, and yard waste is measured under optimum anaerobic decay conditions in a laboratory study (*24*), whose other observations reveal that some portion of the carbon in the waste does not biodegrade and thus this quantity gets sequestered in landfills (*28*). However, there is still a debate on how to account for any biogenic "sequestered" carbon. Issues include the choice of appropriate time frame for sequestration and who should be entitled to potential sequestration credits. While important, this analysis does not assign any credits for carbon sequestered in landfills.

Despite increased recycling efforts, U.S. population growth will ensure that the portion of MSW discarded in landfills will remain significant and growing. Discarded MSW is a viable energy source for electricity generation in a carbon-constrained world. One notable difference between LFGTE and WTE is that the latter is capable of producing an order of magnitude more electricity from the same mass of waste. In addition, as demonstrated in this paper, there are significant differences in emissions on a mass per unit energy basis from LFGTE and WTE. On the basis of the assumptions in this paper, WTE appears to be a better option than LFGTE. If the goal is greenhouse gas reduction, then WTE should be considered as an option under U.S. renewable energy policies. In addition, all LFTGE scenarios tested had on the average higher NO_x, SO_x, and PM emissions than WTE. However, HCl emissions from WTE are significantly higher than the LFGTE scenarios.

Supporting Information Available

MSW composition, physical and chemical characteristics of waste items, detailed LCI tables and sensitivity results, and emission factors for long haul of MSW. This material is available free of charge via the Internet at http://pubs.acs.org.

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Is It Better to Burn or Bury Waste For Clean Electricity Generation?

Supporting Information

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Table S1. Characteristics of Municipal Solid Waste

Category [a]	Discarded Waste, Thousands of Tons	Moisture Content, %[b]	Heating Value, BTU/lb[b]	L_o, L of CH_4 per kg of Waste Item [c]	Biogenic vs. Fossil	Additional Assumptions
Leaves	2,808	60%	2,601	30.6	Biogenic	23% of the total yard waste [d]
Grass	7,448	60%	2,601	136	Biogenic	61% of the total yard waste [d]
Branches	1,954	60%	6,640	62.6	Biogenic	16% of the total yard waste [d]
Old Newsprint	1,340	6%	7,541	74.3	Biogenic	
Old Corr. Cardboard	8,830	5%	6,895	152.3	Biogenic	
Office Paper	2,460	6%	6,313	217.3	Biogenic	
Phone Books	540	6%	6,248	74.3	Biogenic	
Books	860	6%	6,248	217.3	Biogenic	
Old Magazines	1,550	6%	5,386	84.4	Biogenic	
3rd Class Mail	3,740	6%	6,076	150.8	Biogenic	
Mixed Paper	22,650	6%	6,799	103.7	Biogenic	all other paper categories
HDPE	4,720	2%	18,687	0	Fossil	
PET	1,840	2%	18,687	0	Fossil	
Mixed Plastic	12,360	2%	14,101	0	Fossil	all other resins
Ferrous Cans	870	3%	301	0	Biogenic	steel packaging
Ferrous Metal	7,970	3%	0	0	Biogenic	
Aluminum Cans	1,210	2%	0	0	Biogenic	
Aluminum	1,310	2%	0	0	Biogenic	
Glass	8,160	2%	84	0	Biogenic	all glass except durable glass
Food Waste	28,540	70%	1,797	300.7	Biogenic	
CCN [e]	12,620	70%	6,640	0	Biogenic	100% Wood
Plastic – Non-Recyclable	10,000	2%	10,000 [g]		Fossil	100% Carpets
Misc. Organics	10,430	2%	7,730 [h]	0	Biogenic	100% Clothing, 100% Textiles, 100% other non-durables

Table S1. Characteristics of Municipal Solid Waste (Continued)

Category [a]	Discarded Waste, Thousands of Tons	Moisture Content, %[b]	Heating Value, BTU/lb[b]	L_o, L of CH_4 per kg of Waste Item [c]	Biogenic vs. Fossil	Additional Assumptions
CNN [f]	1,800	2%	10,890	0	50% Biogenic / 50% Fossil	100% Rubber tires
Glass - Non-recyclable	1,830	2%	0	0	Biogenic	100% Durable Glass
Misc. Inorganics	15,910	2%	0	0	Fossil	other products, other inorganics, other nonferrous metals, durable plastics
Total MSW	**166,670**	**27%**			**77% Biogenic / 23% Fossil**	

a. Unless stated otherwise in the assumptions column, all the categories are consistent with (1).

b. Source: (2)

c. Source: (3)

d. The split of yard waste into leaves, grass and branches is based on (4).

e. CCN – combustible, compostable, and non-recyclable materials

f. CNN -- combustible, non-compostable, and non-recyclable material

g. Source: (5)

h. Average of heating value of textiles and leather

Table S2. Regulated and Average Emissions Concentrations in the Stack Gas of Waste-to-Energy Facilities

Pollutants	Units	Regulatory Emission Limits [a]	Average at New Facilities [b]
SO_2	(ppmv @ 7% oxygen, dry)	30	10
HCl	(ppmv @ 7% oxygen, dry)	25	11
NO_x	(ppmv @ 7% oxygen, dry)	150	170
CO	(ppmv @ 7% oxygen, dry)	100	100
PM	(mg/dscm @ 7% oxygen, dry)	24	4.7
Dioxins / Furans	(ng/dscm @ 7% oxygen, dry)	13	4.5

a. Source: (6)

b. Source: (7)

Table S3. Emission Factors for Pollutants Exiting from Landfill Gas Control Devices

Pollutant	Units	Flare	Internal Combustion Engine	Turbine
CO	kg/hr/dry standard cubic meter of CH_4/minute	0.72	0.45	0.22
NO_x	kg/hr/dry standard cubic meter of CH4/minute	0.039	0.24	0.083
PM	kg/hr/dry standard cubic meter of CH4/minute	0.016	0.046	0.021
SO_2	kg/hr/dry standard cubic meter of biogas/minute	0.01	0.01	0.01
HCl	kg/hr/dry standard cubic meter of biogas/minute	0.0096	0.0091	0.0098

a. Source: (8)

Table S4. Life-cycle Emission Factors for Landfill Gas to Energy and Waste-to-Energy

		LF-VENT2[a]	LF-VENT2-ICE 15	LF-VENT2-ICE 30	LF-VENT2-ICE 45	LF-VENT2-ICE 60	LF-VENT4[b]	LF-VENT4-ICE 15	LF-VENT4-ICE 30	LF-VENT4-ICE 45	LF-VENT4-ICE 60	LF-VENT 100[c]	WTE-Reg	WTE-Avg
Criteria Pollutants														
CO	g/MWh	4996	6177	3831	3093	2751	5147	6461	3985	3203	2876	326	791	791
NO_x	g/MWh	1217	2804	2233	2053	1969	1334	2994	2352	2150	2065	1015	1286	1453
SO_x	g/MWh	534	801	550	471	434	592	895	610	520	482	528	578	221
PM	g/MWh	238	504	392	356	340	256	533	410	371	355	142	181	60
PM-10	g/MWh	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00	0.00
Other Pollutants														
HCL	g/MWh	35	51	34	29	27	36	53	36	30	28	3	255	112
Dioxins/Furans	g/MWh	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.00	0.00
Ammonia	g/MWh	0.41	0.61	0.42	0.36	0.33	0.45	0.69	0.47	0.40	0.37	0.43	0.00	0.00
Hg	g/MWh	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.05	0.05
Greenhouse gases														
CO_2-biomass	Mg/MWh	2.33	3.49	2.40	2.05	1.89	2.53	3.83	2.61	2.23	2.06	1.77	0.91	0.91
CO_2-fossil	Mg/MWh	0.10	0.15	0.10	0.09	0.08	0.11	0.17	0.12	0.10	0.09	0.11	0.56	0.56
CH_4	Mg/MWh	0.13	0.19	0.13	0.11	0.10	0.16	0.25	0.17	0.14	0.13	0.38	0.00	0.00
CO_2e	$MTCO_2E$/MWh	2.78	4.18	2.87	2.46	2.27	3.55	5.36	3.66	3.12	2.89	8.19	0.56	0.56

Table S4. Life-cycle Emission Factors for Landfill Gas to Energy and Waste-to-Energy (Continued)

		LF-VENT2[a]	LF-VENT2-ICE 15	LF-VENT2-ICE 30	LF-VENT2-ICE 45	LF-VENT2-ICE 60	LF-VENT4[b]	LF-VENT4-ICE 15	LF-VENT4-ICE 30	LF-VENT4-ICE 45	LF-VENT4-ICE 60	LF-VENT 100[c]	WTE-Reg	WTE-Avg
	TWh	11.4	7.6	11.1	12.9	14.0	10.2	6.8	9.9	11.7	12.6	10.8	98.0	98.0
	kWh/ton	-	45.7	66.5	77.6	84.1	-	40.7	59.7	70.0	75.4	-	588	588

a. LF-VENT 2 alternative, potential electricity generated is estimated from the average of LF-VENT 2-ICE 15, -ICE 30, -ICE 45 and –ICE6 that is (7.6+ 11.1+ 12.9+ 14)/4 = 11.4 Twh.

b. LF-VENT 4 alternative, potential electricity generated is estimated from the average of LF-VENT 4-ICE 15, -ICE 30, -ICE 45 and –ICE6 that is (6.8+ 9.9+ 11.7+ 12.6)/4 = 10.2 Twh.

c. LF-VENT 100 alternative, potential electricity generated is estimated from the average of all alternatives, that is 10.8 Twh.

d. CO_2e is represented in metric tons of CO_2 equivalents (MTCO2E) per MWh of electricity generated = $CO_2 + 21 \times CH_4$

Table S5. Life-cycle Emission Factors for Conventional Power Plants

		Coal	Natural Gas	Oil	Nuclear
System Parameters					
Efficiency	%	33	50	33	33
Criteria Pollutants					
CO	g/MWh	216	802	341	27
NO_x	g/MWh	3662	1543	1383	276
SO_x	g/MWh	6891	3391	6075	827
PM	g/MWh	1293	14	119	209
PM-10	g/MWh				
Other Pollutants					
HCl	g/MWh	82	0	22	2
Dioxins/Furans	g/MWh				
Ammonia	g/MWh	0.05	9.11	55.52	0.15
Hg	g/MWh				
Greenhouse gases					
CO_2-biomass	Mg/MWh	0.00	0.00	0.00	0.00
CO_2-fossil	Mg/MWh	0.97	0.41	0.88	0.03
CH_4	Mg/MWh	0.00	0.00	0.00	0.00
CO_2e	MTCO2E/MWh	1.02	0.44	0.89	0.03

Source: (9)

Table S6. Sensitivity of Emission Factors to System Efficiency and Waste Composition

				Sensitivity on				
		Baseline Factors		**System Efficiency**	**Waste Composition**		**Steel Recovery**	
Input Parameters Varied								
Heat Rate	BTU/kWh	18,000	18,000	[11,376, 22,753]	18,000	18,000	18,000	18,000
Efficiency	%	19	19	[15, 30]	19	19	19	19
Composition		Default	Default	Default	All Biogenic	All Fossil	Default	Default
Stack Gas Limits		Reg	Avg	Reg. / Avg.	Reg.	Reg.	Reg	Avg
Steel Recovery		Excludes	Excludes	Excludes	Excludes	Excludes	Includes	Includes
Results: Criteria Pollutants								
HCl	g/MWh	255	112	[71, 322]	237	284	256	113
Dioxins/Furans	g/MWh	8.13E-05	2.82E-05	[1.78E-05, 1.03E-04]	7.57E-05	9.06E-05	8.13E-05	2.82E-05
Ammonia	g/MWh	3.77E-03	3.77E-03	[2.38E-03, 4.76E-03]	4.42E-03	2.71E-03	3.77E-03	3.77E-03
Hg	g/MWh	5.04E-02	5.04E-02	[3.18E-02, 6.37E-02]	6.50E-02	2.65E-02	5.04E-02	5.04E-02

Table S7. Emission Factors for Long Haul of MSW by Heavy Duty Trucks and Rail

		Heavy Duty Trucks	**Rail**
Criteria Pollutants			
CO	g/ton-mile	8.87E-01	1.91E-01
NO_x	g/ton-mile	9.00E-01	3.85E-01
SO_x	g/ton-mile	2.55E-01	8.71E-02
PM	g/ton-mile	1.30E-01	1.08E-01
PM-10	g/ton-mile	NA	NA
Other Pollutants			
HCl	g/ton-mile	NA	NA
Dioxins/Furans	g/ton-mile	NA	NA
Ammonia	g/ton-mile	1.65E-04	5.62E-05
Hg	g/ton-mile	5.77E-07	1.97E-07
Greenhouse gases			
CO_2-biomass	g/ton-mile	2.51E-02	8.57E-03
CO_2-fossil	g/ton-mile	1.05E+02	3.59E+01
CH_4	g/ton-mile	1.67E-02	5.69E-03
CO_2e	MTCO2E/ton-mile	1.05E-04	3.61E-05

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