WHAT COLOUR is YOUR BUILDING?

Measuring and reducing the energy and carbon footprint of buildings

David H. Clark

Appendix A

Energy, CO_2 and climate change

www.whatcolourisyourbuilding.com

Appendix A: Energy, CO_2 and climate change

Finding out that global warming will change the landscape in a part of the world where we don't live is as relevant as finding out that the lesser mottled Tasmanian butterfly is on the verge of extinction. It isn't even worth a shrug.

Jeremy Clarkson, Sunday Times, 16 January 2005.

Contents

This appendix accompanies Chapter 1 (Energy and carbon in buildings) and provides further information on the units of energy and the science of climate change.

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A1. UNITS FOR ENERGY & CARBON

Units of energy

Energy in buildings can be benchmarked in a variety of ways. In this book the units used are $kgCO_2e$ and kWh. Table A.1 shows conversion factors for four units commonly used for energy consumption (kWh, MJ, Btu and toe).

	Kilowatt hours (kWh)	Megajoules (MJ)	British thermal units (kBtu)	Tonnes of oil equivalent (toe)
1 kWh =	1	3.6	3.409	
1 MJ =	0.28	1	0.948	
1 kBtu =	0.00029	0.0011	1	
1 toe =	11,630	41,868	39,680	1

Note: 1 kWh/m^2 is equivalent to 317 Btu/ft^2

Table A.1 Energy unit conversion factors

Energy can occur in different forms, such as electricity, gas or heat. For example, the heat energy required in a building is different to the gas energy used to provide the heat – more gas energy is required due to losses when the boiler converts this fuel into useable heat energy. To avoid confusion, thermal energy units are shown with a suffix in the book:

- kWh_{heat} heating energy
- $kWh_{cooling}$ cooling energy

Primary energy conversion factors

The US Energy Star system and Germany's PassivHaus standard both use Primary Energy as the benchmarking unit instead of carbon. This is the energy in the fuel source, such as coal, oil and gas, as found in its natural state, before conversion to a secondary form of energy such as electricity used in a building (site). Table A.2 shows the factors used in the PassivHaus and Energy Star to convert final (metered) energy consumption into primary energy units.[1]

As with CO_2e factors, there can be variations between published values. A study by Ecofys in 2012 concluded that primary energy factors can be ambiguous and that calculation methods are not harmonised, transparent or consistent.[2] They are also less widely available internationally and not updated as often as CO_2 factors. Primary energy factors, like CO_2e factors, are a useful guide to designing low energy, low carbon buildings, but should not be treated as an absolute.

Fuel	$kWh_{primary}$ / kWh_{final}		
	PassivHaus (UK)	Energy Star (US)	EN 15603 (EU)
Grid electricity	2.7	3.34	3.3
Natural gas	1.1	1.047	1.36
Heating oil	1.1	1.01	-
LPG	1.1	1.01	-
Hard coal	1.1	1.0	1.2
Wood	0.2	1.0	1.1
Electricity from photovoltaics	0.7	-	-
Electricity from hydro power	-	-	1.5
Electricity from nuclear	-	-	2.8
Electricity from coal	-	-	4.05

Table A.2 **Final (site) to primary energy (source) conversion factors**

How to measure the consumption of energy resources

There are three contenders to benchmark energy consumption in buildings:

- Metered energy consumption (kWh).
- Primary energy (kWh).
- CO_2e emissions ($kgCO_2e$).

In buildings, the use of metered energy consumption (kWh) as an energy benchmark rather than primary energy or CO_2e can be misleading when the fuel source or grade of energy (heat or electricity) varies. To illustrate the problem, consider which system has the lowest energy consumption to heat a room in a house – an electric convector heater or gas central heating?

If a space requires 2,000 Watts of heat for 5 hours this is a heat energy requirement of 10 kWh_{heat}. In a simple convector heater an electric current is passed through a wire providing an electrical resistance. This resistance converts the energy in the electric current into heat with an efficiency close to 100%. In a new central heating system the efficiency of converting natural gas into heat energy is approximately 90%.

Table A.3 shows a comparison of the metered energy, CO_2e emissions, running costs and primary energy of the two systems (ignoring fans in a convector heater and pumps in a central heating system).[3]

	Electric convector	Gas boiler	Gas saving
Heat energy required (kWh_{heat})	10	10	
System efficiency	100%	90%	
Metered energy consumption (kWh)	**10.0**	**11.1**	-11%
CO_2e factor ($kgCO_2e/kWh$)	0.6	0.2	
CO_2e emissions ($kgCO_2e$)	**6.0**	**2.2**	63%
Fuel tariff (p/kWh)	12.6 p	3.9 p	
Running cost	**£1.26**	**£0.43**	66%
Primary energy factor	2.7	1.1	
Primary energy consumption (kWh)	**27**	**12.2**	55%

Table A.3 **Comparison of energy, CO_2e and cost for electric v gas domestic heating**

The lowest metered energy consumption (kWh) is from the electric convector heater. But from a running cost, CO_2e emission and primary energy perspective the gas central heating wins hands down. Which system would you choose to heat your house?

An alternative to gas boilers for heating spaces is electric heat pumps (refer Chapter 7 for more details). The efficiency with which a heat pump converts electricity into heat is called the Coefficient of Performance (CoP):

CoP = Heat energy output / Electrical energy input

A heat pump with a CoP of 2.7 converts 1 kWh of electricity into 2.7 kWh_{heat} by extracting (or pumping) heat energy from an external source such as the air or ground.[4] Table A.4 compares a domestic heat pump with a gas boiler.

	Gas boiler	Heat pump	Heat pump saving
Heat energy required (kWh_{heat})	10	10	
System efficiency	90%	270%	
Energy consumption (kWh)	**11.1**	**3.7**	67%
CO_2e factor ($kgCO_2e/kWh$)	0.2	0.6	
CO_2e emissions ($kgCO_2e$)	**2.2**	**2.2**	0%
Fuel tariff (p/kWh)	3.9 p	12.6 p	
Running cost	**£0.43**	**£0.47**	-8%
Primary energy factor	1.1	2.7	
Primary energy consumption (kWh)	**12.2**	**10.0**	18%

Table A.4 **Comparison of energy, CO_2e and cost for heat pump v gas domestic heating**

The primary energy consumption for the heat pump is lower than for the gas boiler but the CO_2e emissions in the UK are similar. Depending on which factors you choose as the efficient measure of energy resources in a building you'll get slightly different conclusions.

There is a large range in the carbon intensity of grid electricity around the world, from 0.1 $kgCO_2e/kWh$ in France (due to extensive use of nuclear power) to 1.4 $kgCO_2e/kWh$ in India (due to coal power stations and high distribution losses).[5] Figure A.1 shows a comparison of CO_2e emissions in different countries for the same heat pump compared with those of a gas boiler. Assuming the infrastructure was in place (not all buildings have access to natural gas) then in India natural gas would be the lowest carbon option, while in France it is electric heat pumps.

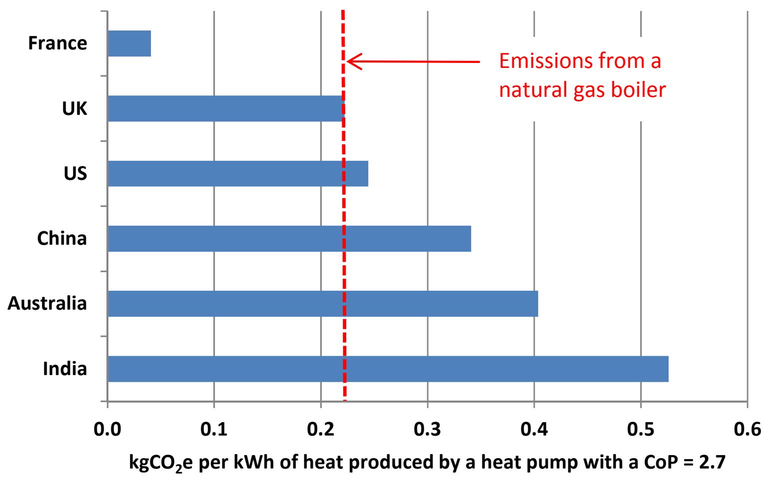


Fig A.1 **Comparison of carbon emissions ($kgCO_2e$) for an electric heat pump connected to grid electricity in different countries**

Low carbon electricity doesn't necessarily mean that there is no impact on the environment. Life cycle assessment (LCA) is widely used in benchmarking the environmental performance of buildings in France to take the significant issues of dealing with nuclear waste into account. In Australia, the high carbon intensity of grid electricity has led to the use of gas CHP in buildings to reduce CO_2e emissions to obtain better energy and green ratings – but this may not be the most efficient use of energy resources, and potentially shifts the emphasis away from energy conservation.

This is one of the reasons why it has been difficult to reach a consensus on how to benchmark the energy and carbon performance of buildings internationally. Should a building's performance be based on how efficiently it uses energy or on the carbon intensity of the grid electricity it is connected to? Ideally it should be a combination of both – and therein lies the challenge.

There is no perfect unit to use and each country must decide on an appropriate approach. The methodologies for benchmarking the whole carbon footprint in Chapter 5 can be applied to buildings in any country using either carbon emissions factors or primary energy factors. The key requirement is to select appropriate factors and then be consistent when applying them to benchmark buildings.

A2. THE SCIENCE OF CLIMATE CHANGE

Reducing the energy consumption and greenhouse gas emissions associated with buildings does not require a detailed understanding of climate change science, in the same way that driving a car does not require an intimate knowledge of aerodynamics, electronics and the workings of the internal combustion engine. However, some people find this interesting, so the following provides a brief overview on the science of global warming and the potential impacts of climate change. In simple terms, the process is:

		Measurement
1	Greenhouse gases (CO_2, CH_4, N_2O & F-gases) are released into the atmosphere. These remain for a long time.	$kgCO_2e$
2	These gases act like a big blanket around the earth preventing heat from escaping into space. The higher the concentration (in parts per million) the thicker the blanket.	CO_2e ppm
3	A number of factors (including greenhouse gases) combine to provide positive (warming) and negative (cooling) radiative forcing effects. The resultant radiative forcing is the difference between energy received from the sun and energy re-radiated back into space.	W/m^2
4	Positive radiative forcing leads to an increase in global mean surface temperatures – global warming.	°C
5	Increasing temperatures cause changes to the climate in different places and in different ways. This may result in hotter summers, colder winters, more droughts, more floods, more extreme weather events, rising sea levels, and so on.	Numerous (financial, societal, environmental)

1. The main greenhouse gases

The three greenhouse gases (GHG) emitted during the combustion of fossil fuels are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). These differ in their warming influence on the global climate system due to their different radiative properties and lifetimes in the atmosphere. These warming influences are typically expressed through a common metric based on the global warming potential of CO_2. The common unit of measurement for these gases is Carbon Dioxide equivalent (CO_2e):

> 1 $kgCO_2e$ is equivalent to the global warming potential of one kilogram of carbon dioxide over a 100 year period.

Figure A.2 shows that the greenhouse gas emissions of commonly used fossil fuels[6] are dominated by CO_2.

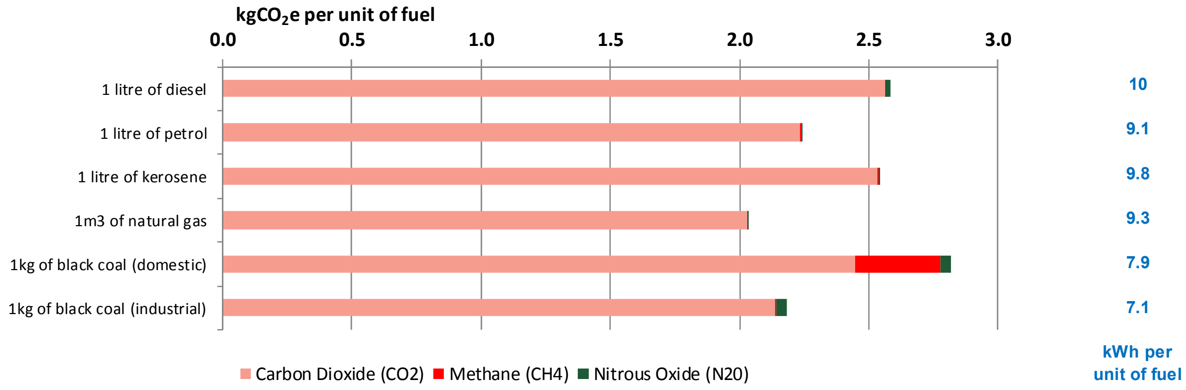


Fig A.2 **Typical greenhouse gas emissions from common fossil fuels**
(the energy released in kWh is shown on the right-hand side)

The three other main greenhouse gases included in the *United Nations Framework Convention on Climate Change* (UNFCCC) are fluorinated gases, known as F-gases.[7] These are often found within buildings (typically the refrigerants used in air conditioning systems). While they are released in negligible quantities compared to CO_2, their global warming potential is significantly greater (some are more than 5,000 times more potent than CO_2) and it is estimated that F-gases represent about 2.8% of the UK's total global warming contribution. In 2006 the European Union introduced legislation to begin the phasing out of the manufacture and use of F-gases.[8]

UK CARBON BUDGETS

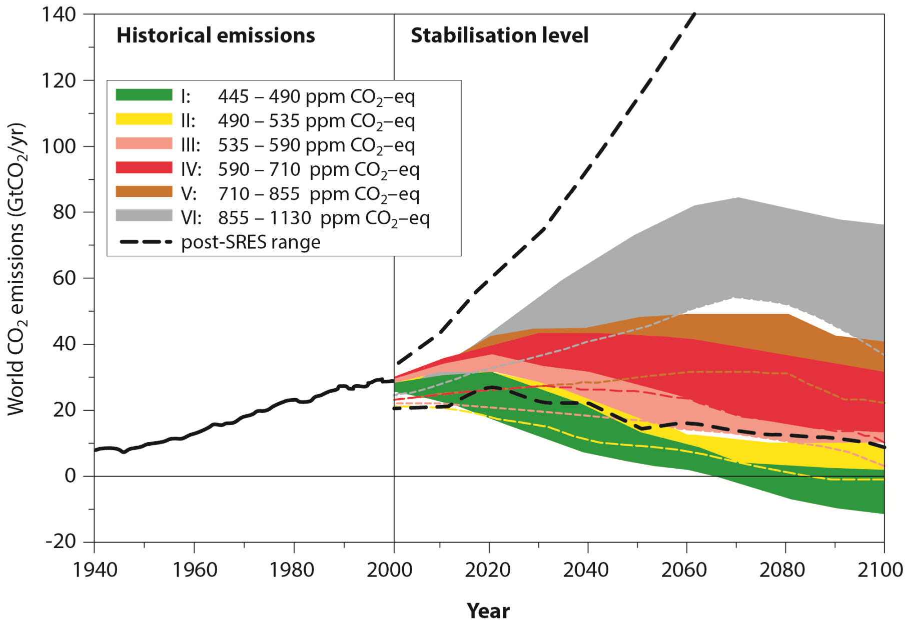
In the Climate Change Act 2008 the UK set legally binding GHG emission reduction targets compared to the Kyoto baseline emissions in 1990 of 780 $MtCO_2e$. These were 22% by 2010, 28% by 2015, 34% by 2020 and 80% by 2050. In 2012 the (provisional) emissions were 572 $MtCO_2e$, a reduction of 26%. In 2011 the emissions were 553 $MtCO_2e$ with the following breakdown: CO_2 (83.5%), CH_4 (7.6%), N_2O (5.3%) and F-gases (2.8%).[9]

2: CO_2 emissions and concentrations

Scientists are reasonably confident about past and current greenhouse gas emissions and concentrations, as they can be physically measured or reasonably estimated. The concentration of CO_2 in the atmosphere in 2010 was 390 ppm, compared to 280 ppm at the start of the industrial revolution in the 1750s.[10]

According to the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report:[11] '*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.*'

Current predictions are that global greenhouse gas emissions aren't going to decrease anytime soon. When the reductions occur, and how deep they are, will determine the concentration of CO_2e when it finally stabilises. The IPCC has considered a number of stabilisation scenarios – categories V to VI are currently the most likely scenarios based on the predicted global demand for fossil fuels over the next 40 years. These are shown in Figure A.3.



Category	Percentage of CO_2 emissions in 2050 compared to 2000	Year that CO_2 emissions peak	CO_2e (including GHGs & aerosols)
I	-85% to -50%	2000 – 2015	445 – 490
II	-60% to -30%	2000 – 2020	490 – 535
III	-30% to +5%	2010 – 2030	535 – 590
IV	+10% to +60%	2020 – 2060	590 – 710
V	+25% to +85%	2050 – 2080	710 – 855
VI	+90% to +140%	2060 – 2090	855 – 1130

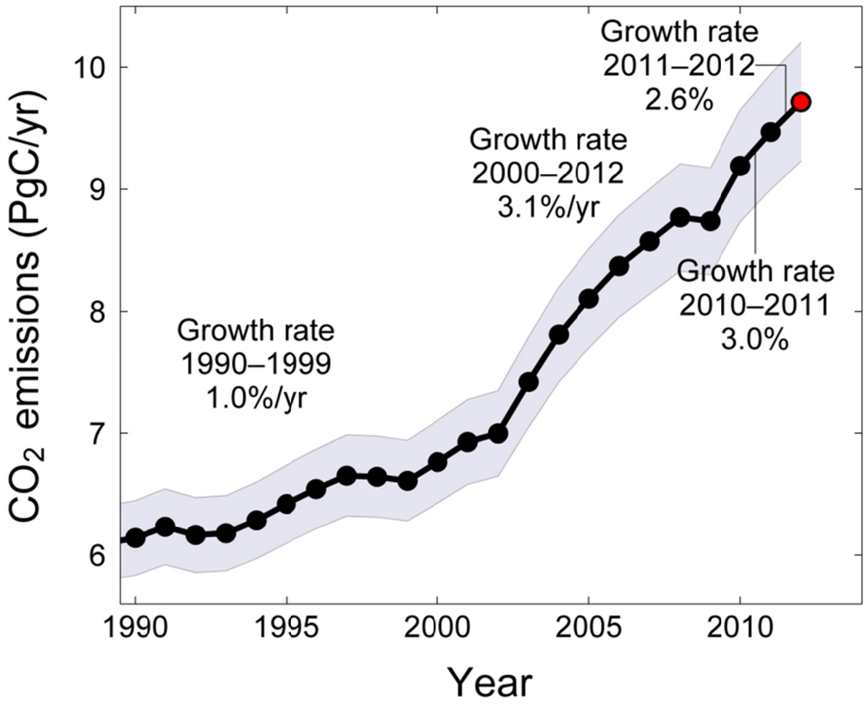
Fig A.3 **CO_2 atmospheric concentrations for different emissions scenarios (Source: Fig 5.1 and Table 5.1, IPCC Synthesis Report 2007)**

HOW DO ACTUAL EMISSIONS COMPARE WITH THE PREDICTIONS?

The Global Carbon Project (www.globalcarbonproject.org) was established in 2001 with a scientific goal to '*develop a complete picture of the global carbon cycle, including both its biophysical and human dimensions together with the interactions and feedbacks between them.*' Each year a Carbon Budget is published which provides an update on global emissions trends. The budget provides data on: atmospheric CO_2 concentrations; emissions from fossil fuels, cement and changes in land use; CO_2 removal by natural sinks (ocean, land); regional emissions; and the effect of the global economic crisis on emissions.

Figure A.4 is taken from the Carbon Budget 2012. Global fossil and cement emissions were 9.5 ± 0.5 PgC in 2011, 54% higher than 1990 levels (the Kyoto reference year). The projection for 2012 is 9.7 ± 0.5 PgC, 58% higher than 1990 levels and the highest so far in human history. Emissions growth is currently tracking at the IPCC's upper emissions scenarios.

The decline in fossil fuel emissions of 1.3% in 2009 was the result of the global financial crisis (GFC) and by 2010 emissions had gone back up with coal accounting for half of the increase. The atmospheric concentration of CO_2 in 2011 was 390 ppm, 39% higher than at the start of the Industrial Revolution (about 280 ppm in 1750).



Uncertainty is ±5% for one standard deviation (IPCC "likely" range)

Fig A.4 **Global carbon emissions due to fossil fuel and cement from 1990 to 2012 (source: Peters et al. 2012a; Le Quéré et al. 2012; CDIAC Data; Global Carbon Project 2012)**

3. Warming (and cooling) from radiative forcing

Greenhouse gases are not the only factor contributing to global warming – but they are the most significant and also currently the most understood because they follow basic laws of physics. Figure A.5 shows the key components influencing both warming and cooling since 1750, their estimated Radiative Forcing impact (RF values in W/m^2) and the Level of Scientific Understanding (LOSU). According to the IPCC: *'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 W/m^2'* with a range of uncertainty between 0.6 and 2.4 W/m^2.

There is less certainty about other contributing anthropogenic (man-made) warming factors such as black carbon[12] and tropospheric ozone, and natural factors such as solar irradiance (the sun's energy). The countervailing cooling effects due to surface albedo (reflectivity) and aerosols also have a low level of scientific understanding, in particular the albedo effect of clouds reflecting the sun's energy back into space. It may turn out that clouds really do have a silver lining and counteract the effect of man-made greenhouse emissions. Relying on this would be a big gamble as there is also a roughly equal chance that it will have less cooling benefit than currently estimated and that global warming will increase further.

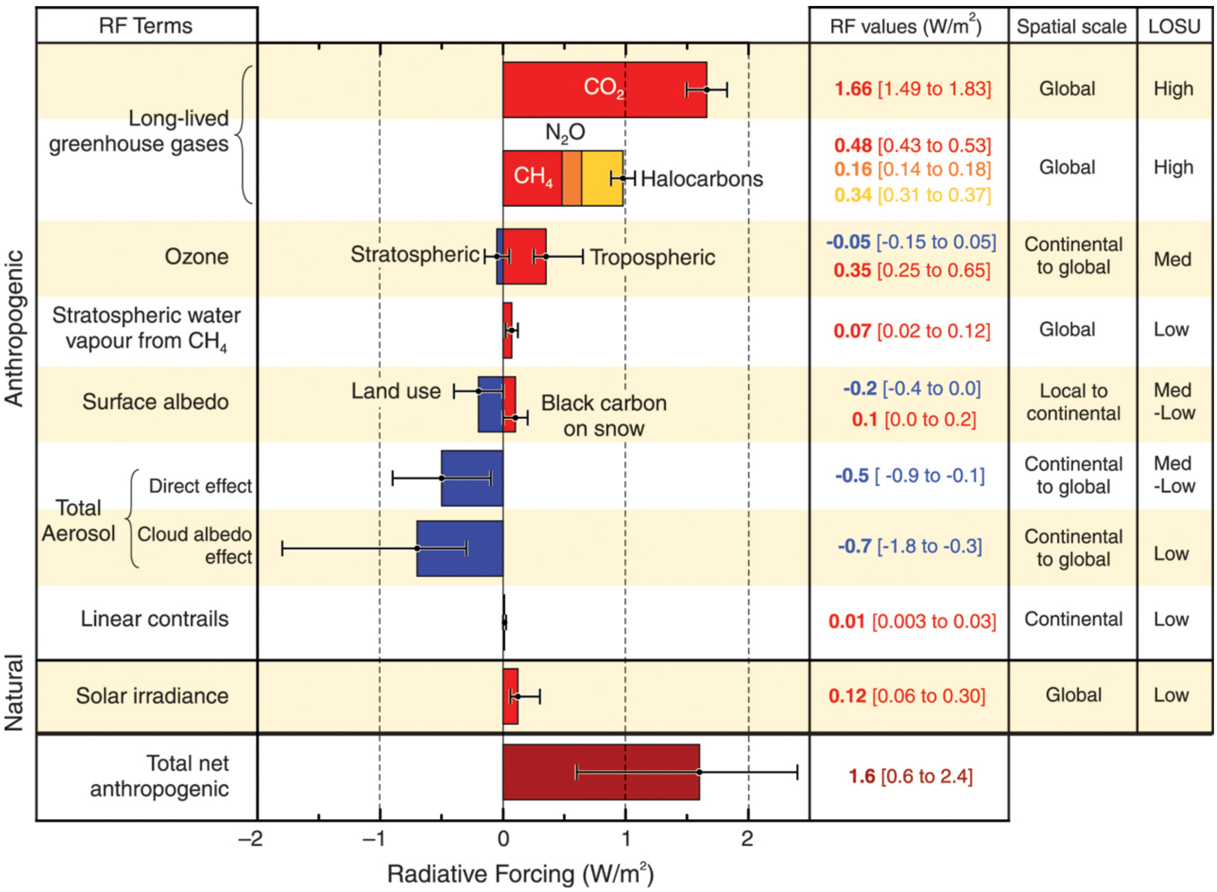


Fig A.5 **Radiative forcing (W/m^2) of the climate between 1750 and 2005 (Source: IPCC 2007 WGI-AR4 Figure SPM.2)**

4. Global warming – temperatures on the up

Radiative forcing (warming) leads to an increase in global average temperatures. Predicting what these temperatures will be, and when they will occur, depends very much on which CO_2e emissions scenario is used (I to IV). Figure A.6, prepared by the IPCC, shows ranges of global average temperature change above pre-industrial temperatures using:

- 'best estimate' climate sensitivity of 3°C (blue line in middle of shaded area),
- upper bound of likely range of climate sensitivity of 4.5°C (red line at top),
- lower bound of likely range of climate sensitivity of 2°C (blue line at bottom).

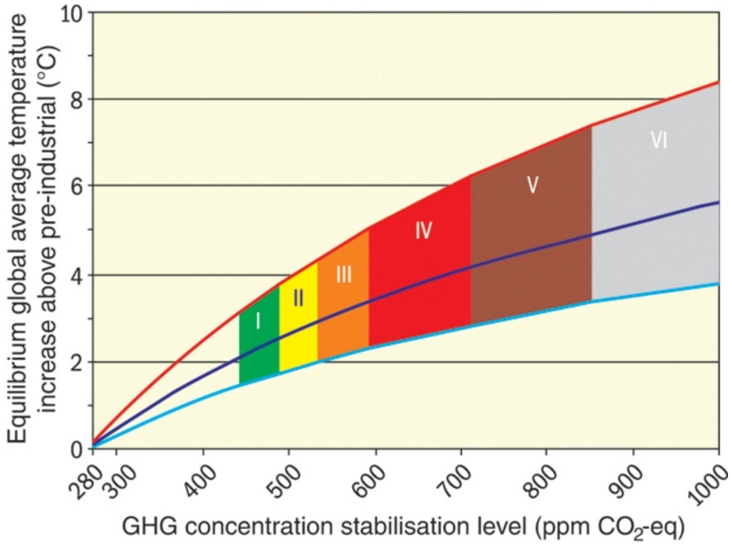


Fig A.6 **Global average temperature increases for different emission scenarios (Source: IPCC 2007 WGIII-AR4 Figure SPM.8)**

Scientists have proposed that to contain global warming, and its risks and consequences, warming compared to pre-industrial times should not exceed 2°C. While the IPCC reports do not establish a specific temperature threshold for dangerous climate changes, in 2009 over one hundred countries adopted this '2°C target' by signing the Copenhagen Accord.[13] To achieve this goal the total CO_2 emissions must be limited to about 1000 $GtCO_2$ between 2000 and 2050 in order to stabilise the concentration of CO_2 at a level no higher than 450 ppm. The emissions in 2050 would have to be about 70% lower than they were in 1990.

Figure A.7 shows fossil CO_2 emissions (top panel) and corresponding global warming (bottom panel) for two possible futures:[14]

- 'Business as usual' (red) – no climate policies are implemented and emissions continue to rise.
- Strong action to reduce emissions (blue) – limits CO_2 emissions related to fossil and land-use to 1000 billion tonnes (Gt) CO_2 between 2000 and 2050 then reduces to near zero emissions by 2100 – similar to IPCC scenario I.

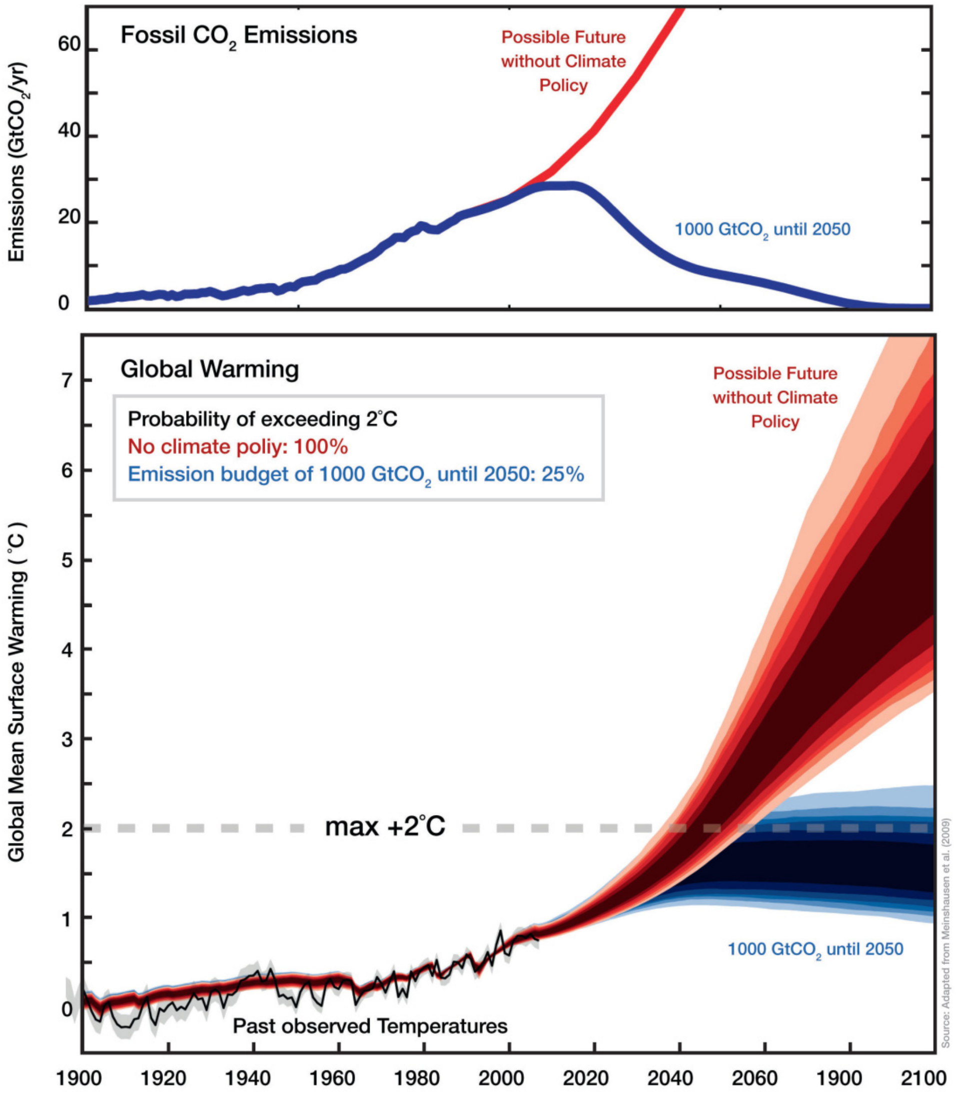


Fig A.7 **CO_2 emissions and global temperature predictions for 'business as usual' (red) and emissions peaking by 2020 then rapidly reducing (blue). (Source: Australian Academy of Science)**

The darkest shaded range for each scenario indicates the most likely temperature rise (50% of simulations fall within this range). Without climate policies global warming is predicted to exceed 2°C by the middle of the century. Strong mitigation actions according to the blue route would limit the risk of exceeding 2°C to around 25%.

The International Energy Agency's *World Energy Outlook 2010*[15] provides a sobering warning: '*the timidity of current commitments has undoubtedly made it less likely that the 2°C goal will be achieved. Reaching that goal would require a phenomenal policy push by governments worldwide: carbon intensity — the amount of CO_2 emitted per dollar of GDP — would have to fall at twice the rate of 1990 – 2008 in 2008 – 2020 and four times faster in 2020 – 2035. The technology exists today to enable such a change, but such a rate of technological transformation would be unprecedented. These commitments must be interpreted in the strongest way possible with much stronger commitments adopted and acted upon after 2020, if not before.*'

5. Estimating the impacts of global warming on climate and sea levels

Climate is the average of weather over time in a particular location. Predicting how rising temperature affects the climate in one region is based on complex modelling and probabilities. Various books and films have raised public awareness of the observed impacts and predictions for climate change including:

- Melting of ice sheets, glaciers and permafrost (which releases trapped methane, further increasing GHG concentrations).
- Reduction in arctic ice coverage (which reduces the albedo effect and so less solar energy is reflected back into space).
- Intensity and frequency of extreme weather events (flooding, hurricanes, heat waves).
- Effects on vegetation cover (desertification, change in species range).
- Effects on insects and animals (extinction, migration patterns, altitude range of insects).
- Increasing sea temperatures (coral bleaching, algae blooms).
- Rising sea levels.

There is no point in going into any of these in detail as there are plenty of books and websites dedicated to describing the potential impacts of climate change. Unfortunately, to get peoples' attention, the media requires a sensational story, so the science on both extremes ('we're heading for disaster' and 'the earth is actually cooling') gets coverage while the calm, rational science in the middle sometimes gets lost.

In *An Inconvenient Truth*[16] there are lots of images showing what would happen to various cities if the seas rose 6 m based on the Greenland ice sheets melting (or half of Greenland and half of Antarctica melting). The IPCC estimates that sea levels will rise between 0.3 and 0.8m *over many centuries* due to thermal expansion if CO_2 is stabilised at year 2000 levels. Estimates for sea level rise at the end of the century for the first four emission stabilisation scenarios (I to IV) are between 0.4 and 2.4 m. The IPCC 2007 report also states: '*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.*'

So the point is that sea levels will rise, but by how much is not well understood (6 m is an extreme estimate), and it will happen gradually over a number of centuries – giving humans plenty of time to adapt (i.e. to move house or build dykes) should we fail completely to limit global warming.

It's good to raise awareness of climate change – but being too alarmist can have the opposite effect and make people sceptical of the rational science behind it.

A3. ARE THE SCEPTICS RIGHT?

It is difficult to get a man to understand something when his salary depends upon his not understanding it.

Upton Sinclair (1878 – 1968)

This statement could apply equally to both sides of the climate change debate – those who get paid to study global warming and those who have a vested interest in maintaining business as usual. Who is right and who can you believe?

Predicting global warming and climate change based on today's concentration of greenhouse gases in the atmosphere generates lots of different scenarios. If you add to this a range of emissions predictions for the next 40 years – will they increase, flatten out or reduce – then the number of permutations and combinations quickly becomes bewildering. Most of the science around CO_2 is robust but for other aspects there is more uncertainty (refer to Figure A.5). All of this opens the door to:

- misuse of statistics – using select (or extreme) numbers to justify one point of view while ignoring other evidence
- procrastination – we need to understand it a bit more before we do anything
- denial – it's a natural process and nothing to do with humans burning fossil fuel
- scepticism – it's probably happening but don't worry about it, we'll just adapt.

LIES, DAMN LIES AND STATISTICS

In September 2010 Deutsche Bank published the report *Climate Change: Addressing the Major Skeptic Arguments* written by scientists at Columbia University's Earth Institute.[17] It lists 12 common claims used to argue against global warming and refutes each of them, pointing readers to corroborating sources. The paper's conclusion is that the primary claims of the sceptics do not undermine the assertion that human-made climate change is already happening and is a serious long-term threat.

Climate change denial has its own Wikipedia page[18] which makes interesting reading. The argument put forward by one side is that most climate deniers have a vested interest in the energy industry (or are funded by it) and are '*conspiring to cover up the threat of man-made climate change, in much the same way the tobacco industry tried to conceal the risks of smoking, by using a series of think tanks and other organisations to falsely sow public doubt in an emerging scientific consensus.*'

The climate change sceptics deny this and argue that there is not a strong scientific consensus that man-made greenhouse gas emissions are causing damaging climate change. Have a read through their various websites[19] and make your own mind up about who to believe.

The wisdom of Donald Rumsfeld[20] can be applied to climate change science: '*There are known knowns. These are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. These are things we do not know we don't know.*'

So what do we know? The most recent IPCC report on Climate Change in 2007 made the following statements:

- Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures.
- 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.
- Global greenhouse gas emissions due to human activities have grown since pre-industrial times, with an increase of 70% between 1970 and 2004.
- 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 W/m^2.

The consensus of so many peer reviewed climate scientists makes a fairly compelling argument. The evidence suggests that global warming, and consequently climate change, is happening, that it's basically our fault and that there are lots of things we could do to reduce man-made greenhouse gas emissions (which are the biggest contributor to global warming).

No one (least of all the scientists) denies that there are lots of uncertainties in climate science (the known unknowns) and research continues to find more accurate answers.[21] There are also some really big technologies which might solve the problem without us having to change our energy habits, such as large-scale carbon capture or climate engineering.[22] We just don't know if they'll actually work!

And of course there must be lots of things that we're completely ignorant of where climate change is concerned (the unknown unknowns). Maybe there is some feedback loop that will stabilise the earth's climate irrespective of CO_2 emissions – or maybe there is a mechanism that accelerates change even faster than currently estimated.

Putting climate change to one side, at some point in the future we'll have to find alternative energy sources because fossil fuels won't last forever. So even if climate change is found to be a minor inconvenience which we'll just have to adapt to, it doesn't alter the fact that we really aren't making smart use of the earth's finite resources.

If climate change does turn out to be a big deal, and most evidence suggests that it will, then is it sensible to do nothing to reduce its impact because there are a few things that we don't know at the moment?

THE SCEPTICAL ENVIRONMENTALIST?

In 2001, Bjorn Lomborg published The Skeptical Environmentalist, which gained a lot of media attention. The main thrust of the book was that many of the scientific claims on climate change were wrong, the consequences wouldn't be as dire as predicted, and that the world had more pressing social and environmental issues to tackle. Since that time his stance towards the urgency of tackling climate change appears to have gradually shifted.

In Cool It (2007) he stated that '*global warming is real and man-made. It will have a serious impact on humans and the environment toward the end of this century.*' He then argued that '*the cost and benefits of the proposed measures against global warming... is the worst way to spend our money. Climate change is a 100-year problem — we should not try to fix it in 10 years.*'

In an article in Esquire magazine (October 2008) he wrote: '*The main environmental challenge of the 21st century is poverty. When you don't know where your next meal is coming from, it's hard to consider the environment 100 years down the line. When your kids are starving, you will slash-and-burn the rain forest; when you're rich, you'll be a web designer and vote green.*'

In Smart Solutions to Climate Change: Comparing Costs and Benefits (2010), he wrote: '*We have long moved on from any mainstream disagreements about the science of climate change. The crucial, relevant conversation of today is about what to do about climate change – the economics of our response. If the global community wants to spend up to, say, $250 billion per year over the next 10 years to diminish the adverse effects of climate changes, and to do most good for the world, which solutions would yield the greatest net benefits?*'

This last question is a very valid one – what is the best way to spend money to tackle climate change?

Notes

All websites were accessed on 6 May 2013 unless noted otherwise. Information papers referenced are available to download from www.wholecarbonfootprint.com.

1. The primary energy factors are taken from:
   - PassivHaus PHPP software 2007. www.passivhaus.org.uk/page.jsp?id=25
   - *ENERGY STAR Performance Ratings Methodology for Incorporating Source Energy Use* downloaded from www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs
   - EN15603:2008 Annex E (based on data from 1996)

2. Ecofys press release dated 21 March 2012. *www.ecofys.com/en/press/high-primary-energy-factors-jeopardizes-renewable-energy-development/*

3. Refer to Appendix B for emissions factors. The electricity and gas tariffs are based on the author's home energy bills in October 2012.

4. The EU considers heat pumps to be renewable if they have a minimum CoP between 2.6 and 3.1 depending on the type. Field trials in 2009 suggest typical domestic heat pumps in the UK have an average CoP of around 2.2 with the best recorded at 3.2. Adopting a CoP of 2.7 (midway between average and best) for comparison of a typical heat pump with an efficient gas boiler for heating therefore appears a reasonable assumption. Refer to Chapter 7 for further discussion and evaluation of heat pumps.

5. Refer to Appendix B.

6. Emission factors and energy values from 2012 Guidelines to DEFRA / DECC's GHG Conversion Factors for Company Reporting. Refer to Appendix B for more details on emission factors.

7. The F-gases included in GHG reporting under the UNFCCC are Hydrofluorocarbons (HFC), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6). http://unfccc.int/ghg_data/ghg_data_unfccc/items/4146.php.

   Globally F-gases account for about 1% of greenhouse emissions. In the UK they account for about 2.8% (refer to end note 9). Refer to Appendix B for further details on emissions from F-gases in buildings.

8. http://ec.europa.eu/clima/policies/f-gas/index_en.htm. The proposal to phase out F-gases due to their Global Warming Potential (GWP) has parallels with the Montreal Protocol which phased out the use of CFCs and HCFCs refrigerants due to their Ozone Depletion Potential (ODP).

9. *2012 UK greenhouse gas emissions, provisional figures* and *2011 UK greenhouse gas emissions, final figures by fuel type and end-user*, a statistical release by Department of Energy and Climate Change dated 28th March 2013.

10. Global Carbon Project Carbon Budget 2010. www.globalcarbonproject.org

11. *Climate Change 2007, the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC),* is the fourth in a series of reports intended to assess scientific, technical and socio-economic information concerning climate change, its potential effects, and options for adaptation and mitigation. The Climate Change 2007 report is released in four sections:
    - AR4 Synthesis Report – includes a summary for policy makers.
    - Working Group I Report (WGI): The Physical Science Basis.
    - Working Group II Report (WGII): Impacts, Adaptation and Vulnerability.
    - Working Group III Report (WGIII): Mitigation of Climate Change.

    The graphs used in Chapter I are all taken from the Synthesis Report unless stated otherwise. www.ipcc.ch

12. Refer to Information Paper 5 – Global Warming due to black carbon for further information.

13. Refer to the Decision 2/CP15, known as the Copenhagen Accord, in the United Nation's Framework Convention on Climate Change Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009 Addendum, Part Two: Action taken by the Conference of the Parties at its fifteenth session.

14. The chart is Figure 5.1 from the *2010 The Science of Climate Change: Questions and Answers, Australian Academy of Science* - adapted from Meinshausen et al. (2009). www.science.org.au.

15. The International Energy Agency publishes the World Energy Outlook each year. The quotation was taken from the *World Energy Outlook 2010 Factsheet* downloaded from the website www.worldenergyoutlook.org on 29 November 2010.

16. *An Inconvenient Truth* is a book and a film documentary made by Al Gore in 2006.

17. www.dbcca.com/dbcca/EN/_media/DBCCAColumbiaSkepticPaper090710.pdf

18. http://en.wikipedia.org/wiki/Climate_change_denial

19. Websites include www.climategate.com, www.climatedepot.com, www.climate-skeptic.com, and www.anhonestclimatedebate.wordpress.com.

20. Statement made at a press briefing given by former US Defence Secretary Donald Rumsfeld on 12 February 2002.

21. The fifth version of the IPCC Assessment Report (AR5) will be finalised in 2014. It will put a greater emphasis on the socio-economic aspects of climate change and the implications for sustainable development, risk management and the framing of a response through both adaptation and mitigation.

22. Carbon capture and storage is a technique to capture carbon dioxide from large point sources, such as fossil fuel power plants, and then store it underground in such a way that it does not enter the atmosphere. The feasibility of implementing this on a large scale (technical and cost) is yet to be proven.

    Climate engineering (sometimes known as geo-engineering) is the large-scale engineering of our environment in order to reduce or mitigate global warming. Proposed techniques include:

    - Reducing atmospheric CO_2 through:
      - ocean iron fertilisation
      - carbon capture.
    - Reducing solar radiation:
      - creating stratospheric sulphur aerosols
      - cool roofs - using pale-coloured roofing and paving materials
      - cloud reflectivity enhancement - using fine sea water spray to whiten clouds and increase cloud reflectivity
      - space sunshade – obstructing solar radiation with space-based mirrors or other structures
      - cloud seeding of cirrus clouds, possibly using airliners.

    No large-scale projects have yet been undertaken. There are various technical, financial, environmental and ethical challenges to be overcome.