

Growth isn't possible

Why we need a new economic direction



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Foreword

If you spend your time thinking that the most important objective of public policy is to get growth up from 1.9 per cent to 2 per cent and even better 2.1 per cent we're pursuing a sort of false god there. We're pursuing it first of all because if we accept that, we will do things to the climate that will be harmful, but also because all the evidence shows that beyond the sort of standard of living which Britain has now achieved, extra growth does not automatically translate into human welfare and happiness.

Lord Adair Turner¹
Chair of the UK Financial Services Authority

Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist.

Kenneth E. Boulding
Economist and co-founder of General Systems Theory

In January 2006, **nef** (the new economics foundation) published the report *Growth isn't working*.² It highlighted a flaw at the heart of the general economic strategy that relies upon global economic growth to reduce poverty. The distribution of costs and benefits from economic growth, it demonstrated, are highly unbalanced. The share of benefits reaching those on the lowest incomes was shrinking. In this system, paradoxically, in order to generate ever smaller benefits for the poorest, it requires those who are already rich and 'over-consuming' to consume ever more.

The unavoidable result under business as usual in the global economy is that, long before any general and meaningful reduction in poverty has been won, the very life-support systems that we all rely on are almost certain to have been fundamentally compromised.

Four years on from *Growth isn't working*, this new publication, *Growth isn't possible* goes one step further and tests that thesis in detail in the context of climate change and energy. It argues that indefinite global economic growth is unsustainable. Just as the laws of thermodynamics constrain the maximum efficiency of a heat engine, economic growth is constrained by the finite nature of our planet's natural resources

(biocapacity). As economist Herman Daly once commented, he would accept the possibility of infinite growth in the economy on the day that one of his economist colleagues could demonstrate that Earth itself could grow at a commensurate rate.³

Whether or not the stumbling international negotiations on climate change improve, our findings make clear that much more will be needed than simply more ambitious reductions in greenhouse gas emissions. This report concludes that a new macro economic model is needed, one that allows the human population as a whole to thrive without having to relying on ultimately impossible, endless increases in consumption.

Andrew Simms
Victoria Johnson
January 2010

Introduction

We really have to come up with new metrics and new measures by which we look at economic welfare in a much larger context than just measuring GDP, which I think is proving to be an extremely harmful way of measuring economic progress.

R K Pachauri Ph.D,⁴ Chairman, Intergovernmental Panel on Climate Change
Director-General, The Energy and Resources Institute,
Director, Yale Climate and Energy Institute

Towards what ultimate point is society tending by its industrial progress? When the progress ceases, in what condition are we to expect that it will leave mankind?

John Stuart Mill (1848)⁵

From birth to puberty a hamster doubles its weight each week. If, then, instead of levelling-off in maturity as animals do, the hamster continued to double its weight each week, on its first birthday we would be facing a nine billion tonne hamster. If it kept eating at the same ratio of food to body weight, by then its daily intake would be greater than the total, annual amount of maize produced worldwide.⁶ There is a reason that in nature things do not grow indefinitely.

The American economist Herman Daly argues that growth's first, literal dictionary definition is '...to spring up and develop to maturity. Thus the very notion of growth includes some concept of maturity or sufficiency, beyond which point physical accumulation gives way to physical maintenance'.⁷ In other words, development continues but growth gives way to a state of dynamic equilibrium – the rate of inputs are equal to the rate of outputs so the composition of the system is unchanging in time.⁸ For example, a bath would be in dynamic equilibrium if water flowing in from the tap escapes down the plughole at the same rate. This means the total amount of water in the bath does not change, despite being in a constant state of flux.

In January 2006, **nef** (the new economics foundation) published the report *Growth isn't working*.⁹ It highlighted a flaw at the heart of the economic strategy that relies overwhelmingly upon economic growth to reduce poverty. The distribution of costs and benefits from global economic growth, it demonstrated, are highly unbalanced. The

share of benefits reaching those on the lowest incomes was shrinking. In this system, paradoxically, in order to generate ever smaller benefits for the poorest, it requires those who are already rich and 'over-consuming' to consume ever more.

The unavoidable result, the report points out, is that, with business as usual in the global economy, long before any general and meaningful reduction in poverty has been won, the very life-support systems we all rely on are likely to have been fundamentally compromised.

Four years on from *Growth isn't working*, *Growth isn't possible* goes one step further and tests that thesis in detail in the context of climate change and energy. It argues that indefinite global economic growth is unsustainable. Just as the laws of thermodynamics constrain the maximum efficiency of a heat engine, economic growth is constrained by the finite nature of our planet's natural resources (biocapacity). As Daly once commented, he would accept the possibility of infinite growth in the economy on the day that one of his economist colleagues could demonstrate that Earth itself could grow at a commensurate rate.¹⁰

The most recent data on human use of biocapacity sends a number of unfortunate signals for believers in the possibility of unrestrained growth. Our global ecological footprint is growing, further overshooting what the biosphere can provide and absorb, and in the process, like two trains heading in opposite directions, we appear to be actually shrinking the available biocapacity on which we depend.

Globally we are consuming nature's services – using resources and creating carbon emissions – 44 per cent faster than nature can regenerate and reabsorb what we consume and the waste we produce. In other words, it takes the Earth almost 18 months to produce the ecological services that humanity uses in one year. The UK's footprint has grown such that if the whole world wished to consume at the same rate it would require 3.4 planets like Earth.¹¹

Growth forever, as conventionally defined (see Box 1), within fixed, though flexible, limits isn't possible. Sooner or later we will hit the biosphere's buffers. This happens for one of two reasons. Either a natural resource becomes over-exploited to the point of exhaustion, or because more waste is dumped into an ecosystem than can be safely absorbed, leading to dysfunction or collapse. Science now seems to be telling us that both are happening, and sooner, rather than later.

Yet, for decades, it has been a heresy punishable by career suicide for economists (or politicians) to question orthodox economic growth. As the British MP Colin Challen

Box 1: What is growth?

The question is deceptive, because the word has many applications. They range from the description of biological processes to more abstract notions of personal development. But, when used to describe the economy, growth has a very specific meaning. This often causes confusion.

Growth tends to be used synonymously with all things that are good. Plants grow, children grow, how could that be bad? But, of course, even in nature, growth can be malign, as in the case of cancer cells.

In economics 'growth', or the lack of it, describes the trajectory of Gross Domestic Product and Gross National Product, two slightly different measures of national income (they differ, basically, only in that one includes earnings from overseas assets). The value of imports is deducted and the value of exports added.

Hence, an economy is said to be growing if the financial value of all the exchanges of goods and services within it goes up. The absence of growth gets described, pejoratively, as recession. Prolonged recessions are called depressions.

Yet, it is not that simple. An economy may grow, for example, because money is being spent on clearing up after disasters, pollution, to control rising crime or widespread disease. You may also have 'jobless growth,' in which the headline figure for GDP rises but new employment is not generated, or environmentally destructive growth in which a kind of false monetary value is created by liquidating irreplaceable natural assets on which livelihoods depend.

The fact that an economy is growing tells you nothing about the 'quality' of economic activity that is happening within it. Conversely, history shows that in times of recession, life expectancy can rise, even as livelihoods are apparently harmed. This happens in rich countries probably due to force of circumstances, as people become healthier by consuming less and exercising more, using cheaper, more active forms of transport such as walking and cycling.

It is possible, in other words, to have both 'economic' and 'uneconomic' growth and we should not assume that growth *per se* is a good thing, to be held on to at all costs.

quipped in 2006, 'We are imprisoned by our political Hippocratic oath: we will deliver unto the electorate more goodies than anyone else.'¹²

The growth debate: historical context

There is a kind of reverse political correctness that prevents growth being debated properly. Yet this has not always been true. Historically, there have been vigorous debates on the optimal scale for the economy, which we survey briefly towards the end of this report (also summarised in Box 2).

More familiarly, the 1960s and early 1970s saw a vigorous debate on the environmental implications of growth. But this was sometimes hampered by insufficient data. Scientists at the Massachusetts Institute of Technology (MIT) were commissioned by the Club of Rome to research and publish the controversial *Limits to growth*, which came out in 1972. Since then, the original report has been successively revised and republished.

Matthew Simmons, founder of the world's largest energy investment banking firm, commented on publication of the 2004 update that its message was more relevant than ever and that we, 'wasted 30 valuable years of action by misreading the message of the first book'.¹³ Originally dismissed and criticised for 'crying wolf', the report has, in fact, stood the test of time. A study in 2008 by physicist Graham Turner from CSIRO (Commonwealth Scientific and Industrial Research Organisation), Australia's leading scientific research institute, compared its original projections with 30 years of subsequent observed trends and data.¹⁴ His research showed that they 'compared favourably'.

Less well known is that in this fairly recent period, there was also a significant debate on the desirability of economic growth from the point of view of social and individual, human well-being.^{15,16,17} It is disciplines other than economics that have seemed able to view the issue of growth less dogmatically, asking difficult questions and making inconvenient observations, their views apparently less constrained by hardened doctrine.

For example, the implications of 'doubling', graphically represented by our voracious hamster, were addressed in May 2007 by Roderick Smith, Royal Academy of Engineering Research Professor at Imperial College, London. The physical view of the economy, he said, 'is governed by the laws of thermodynamics and continuity', and so, 'the question of how much natural resource we have to fuel the economy, and how much energy we have to extract, process and manufacture is central to our existence.'¹⁸

Engineers must deal every day with the stuff, the material, the 'thingyness' of the world around them, the stresses and strains that make things stand up, fall down, last or wear out. Because of this, they are perhaps more in tune with the real world of resources than the economist working with abstract mathematical simplifications of life.

Hence Smith honed in on one of the economy's most important characteristics – its 'doubling period', by which its bulk multiplies in proportion to its current size. Even low growth rates of around 3 per cent, he points out, lead to 'surprisingly short doubling times'. Hence, 'a 3 per cent growth rate, which is typical of the rate of a developed economy, leads to a doubling time of just over 23 years. The 10 per cent rates of rapidly developing economies double the size of the economy in just under 7 years.'

But then, if you are concerned about humanity's ecological debt, comes what Smith quaintly calls the 'real surprise'. Because, according to Smith, 'each successive doubling period consumes as much resource as all the previous doubling periods combined', just as 8 exceeds the sum of 1, 2 and 4. Adding, almost redundantly, as jaws in the room fall open, 'this little appreciated fact lies at the heart of why our current economic model is unsustainable.'

Why do economies grow?

We should ask the simple question, why do economies grow? And, why do people worry that it will be a disaster if they stop? The answers can be put reasonably simply.

For most countries in much of human history, having more stuff has given human beings more comfortable lives. Also, as populations have grown, so have the economies that housed, fed, clothed and kept them.

Yet, there has long been an understanding in the quiet corners of economics, as well as louder protests in other disciplines, that growth cannot and need not continue indefinitely. As John Stuart Mill put it in 1848, 'the increase of wealth is not boundless: that at the end of what they term the progressive state lies the stationary state.'¹⁹

The reasons for growth not being 'boundless' too, have been long known. Even if the modern reader has to make allowances for the time in which Mill wrote, his meaning remains clear: 'It is only in the backward countries of the world that increased production is still an important object: in those most advanced, what is economically needed is a better distribution.'²⁰

Box 2. No-growth economics: a select chronology of books and papers

In contemplating any progressive movement, not in its nature unlimited, the mind is not satisfied with merely tracing the laws of the movement; it cannot but ask the further question, to what goal? Towards what ultimate point is society tending by its industrial progress? When the progress ceases, in what condition are we to expect that it will leave mankind?

It must always have been seen, more or less distinctly, by political economists, that the increase of wealth is not boundless: that at the end of what they term the progressive state lies the stationary state, that all progress in wealth is but a postponement of this, and that each step in advance is an approach to it.²¹

John Stewart Mill, 1848

- 1821 *On the principles of political economy and taxation* (3rd edition) by David Ricardo (on the ‘Stationary State’)
- 1848 *Principles of political economy* by John Stuart Mill (on the ‘Stationary State’, in Book IV, Chapter VI)
- 1883 *Human labour and the unit of energy* by Sergei Podolinsky
- 1922 *Cartesian economics* by Frederick Soddy
- 1967 *The costs of economic growth* by E J Mishan
- 1971 *The entropy law and the economic process* by Nicholas Georgescu-Roegen
- 1972 *Limits to growth: A report for the Club of Rome’s project on the predicament of mankind* by Donella Meadows
- 1973 *Small is beautiful: A study of economics as if people mattered* by E F Schumacher
- Toward a steady state economy* by Herman E Daly (ed)
- 1977 *The economic growth debate: An assessment* by E J Mishan
- Social limits to growth* by Fred Hirsch
- 1978 *The economic growth debate: Are there limits to growth?* By Lawrence Pringle

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- 1982 *Overshoot* by William R Catton
- 1987 *Our common future* by the World Commission on Environment and Development
- 1989 *Beyond the limits to growth: A report to the Club of Rome* by Eduard Pestel
- 1992 *The growth illusion: How economic growth has enriched the few, impoverished the many, and endangered the planet* by Richard Douthwaite and Edward Goldsmith
- 1995 *Our ecological footprint: Reducing human impact on the Earth* by William Rees and Mathis Wackernagel
- 1996 *Beyond growth* by Herman E Daly
- 1997 *Sustainable development: Prosperity without growth* by Michael J Kinsley
- 2004 *Limits to growth: The 30 year update* by Donella Meadows, Jorgen Randers and Dennis Meadows
Growth fetish by Clive Hamilton
- 2005 *Ecological debt: The health of the planet and the wealth of nations* by Andrew Simms
- 2006 *Growth isn't working: The unbalanced distribution of benefits and costs from economic growth* by David Woodward and Andrew Simms
- 2009 *Prosperity without growth* by Tim Jackson
- 2010 *Growth isn't possible* by Andrew Simms, Victoria Johnson and Peter Chowla.

So why is it, that over 160 years after Mill wrote those words, rich nations are more obsessed than ever with economic growth?

Countries like the UK are decades past the point where increases in national income, measured by GNP and GDP lead to similar increases in human well-being and life expectancy.²² Yet no mainstream politician argues against the need for economic growth.

The reasons are partly to do with policy habits, partly political posturing, and partly because we have set our economic system up in such a way that it has become addicted to growth.

Growth-based national accounting became popular in the 1930s as a guide to quantify the value of government interventions to rescue economies from the depression, and also later as a tool to aid increased production as part of the war planning effort. But the new measurement came with a very big health warning attached.

One of the indicator's key architects, the economist Simon Kuznets, was explicit about its limitations. Growth did not measure quality of life, he made clear, and it excluded vast and important parts of the economy where exchanges were not monetary. By this he meant, family, care and community work – the so-called 'core economy' which makes society function and civilisation possible.²³ So, for example, if the money economy grows at the expense of, and by cannibalizing the services of the core economy – such as in the way that profit driven supermarkets grow at the expense of communities – it is a kind of false growth. Similarly if the money economy grows simply by liquidating natural assets that are treated as 'free income' this, too, is a kind of 'uneconomic growth'.

Also, it was repeatedly observed that growth in aggregate national income couldn't tell you anything about the nature of the economy, whether activity was good or bad. Spending on prisons, pollution and disasters pushed up GDP just as surely as spending on schools, hospitals and parks. But growth nevertheless became the eclipsing indicator of an economy's virility and success. Even though, in 1968, Robert Kennedy pointed out that growth measured everything apart from 'that which makes life worthwhile'.²⁴

The problem with our economic system is now threefold. First, governments plan their expenditure assuming that the economy will keep growing. If it then didn't grow, there would be shortfalls in government income with repercussions for public spending. The same is true for all of us; for example, when we plan for old age by putting our savings into pensions.

Today, though, many economies like the UK are facing this problem in any case. Ironically, however, it comes as a direct consequence of the economic damage caused by the behaviour of weakly regulated banks, which were busy chasing maximum rates of growth through financial speculation.

Secondly, neo-liberal economies typically put legal obligations on publicly listed companies to grow. They make the maximisation of returns to shareholders the

Box 3. Climate change is not the only limit

This report focuses mainly on how the need to preserve a climate system that is conducive to human society puts a limit on orthodox economic growth. But climate change is not the only natural parameter. Other limits of our biocapacity also need respecting if we are to maintain humanity's environmental life support system. Two important areas of research, described below, provide examples of attempts to define some of those limits and raise questions for economists and policy makers.

The Ecological Footprint²⁵

From a methodology first developed by the Canadian geographer William Rees in the early 1980s, the ecological footprint is now a well-established technique being constantly refined as available data and understanding of ecosystems improves. It compares the biocapacity available to provide, for example, farmland, fisheries and forestry, as well as to absorb waste from human economic activity, with the rate at which humanity consumes those resources and produces waste, for example in the form of greenhouse gas emissions.

The 2009 set of Global Footprint Accounts reveal that the human population is demanding nature's services, using resources and generating CO₂ emissions, at a rate that is 44 per cent faster than what nature can replace and reabsorb. That means it takes the Earth just under 18 months to produce the ecological services humanity needs in one year. Very conservatively, for the whole world to consume and produce waste at the level of an average person in the United Kingdom, we would need the equivalent of at least 3.4 planets like earth. Most worryingly there are signs that available biocapacity is actually reducing, being worn out, by current levels of overuse, setting up a negative spiral of overconsumption and weakening capacity to provide.

Planetary boundaries

A much more recent approach, published in science journal *Nature* in September 2009, uses the notion of 'planetary boundaries.'²⁶ The work, co-authored by 29 leading international scientists, identifies nine processes in the biosphere for which the researchers considered it necessary to 'define planetary boundaries'. They are:

- climate change;
- rate of biodiversity loss (terrestrial and marine);
- interference with the nitrogen and phosphorus cycles;
- stratospheric ozone depletion;
- ocean acidification;
- global freshwater use;
- change in land use;
- chemical pollution; and
- atmospheric aerosol loading

Of these nine, the authors found that three boundaries had already been transgressed: climate change, interference with the nitrogen cycle, and biodiversity loss (see Table 1).

Setting boundaries is complex. Earth systems change and react in often non-linear ways. The erosion or overburdening of one system can affect the behaviour and resilience of another. As the research points out, ‘If one boundary is transgressed, then other boundaries are also under serious risk. For instance, significant land-use changes in the Amazon could influence water resources as far away as Tibet.’

Nevertheless, and even though with caveats, the authors identify boundaries for seven of the nine processes leaving the safe thresholds for atmospheric aerosol loading and chemical pollution still ‘to be identified.’

The work on planetary boundaries complements (although unusually doesn’t reference) the ecological footprint method. The latter, due to a lack of previous research on safe rates of harvest and waste dumping, merely produces a best assessment of full available biocapacity and compares it to human rates of consumption and waste generation. This conservatively, or rather generously, creates the impression that all biocapacity might be available for human use. The attempt to define more nuanced planetary boundaries concerning different earth systems, is set to produce more realistic, and almost inevitably smaller assessments of the share of the earth’s resources and services available for safe human economic use.

Table 1. Identifying planetary boundaries that should not be crossed. Limits for earth processes in grey have already been transgressed.

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(1) Atmospheric CO ₂ concentration (ppm)	350	387	280
	(2) Change in radiative forcing (Wm ⁻²)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species yr ⁻¹)	10	>100	0.1-1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N ₂ removed from the atmosphere for human use (Mt yr ⁻¹)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (Mt yr ⁻¹)	11	8.5-9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.9	3.44
Global freshwater use	Consumption of freshwater by humans (km ³ yr ⁻¹)	4000	2600	415
Change in land use	% of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis	To be determined		
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof	To be determined		

Source: Rockström *et al.* 2009

highest priority for management. As major investors are generally footloose, they are free to take their money wherever the highest rates of return and growth are found.

Thirdly, in the modern world, money is lent into existence by banks with interest rates attached. Because for every pound, dollar, yen or euro borrowed, more must be paid

back, economies that function largely on interest-bearing money have a built-in growth dynamic.

The problem extends beyond the economy. Our increasingly consumerist society demands ever higher consumption to demonstrate social status – conspicuous consumption.²⁷ To see how advanced, industrialised nations might escape from a locked-in growth dynamic, see the conclusion to this report.

First principles – the laws of thermodynamics

The first law says you can't win, the second law says you can't even break even

C.P. Snow.

The physicist and novelist C.P. Snow became famous for trying to bridge the gap between the 'two cultures', science and the arts. When he described the alleged division, he made reference to the failure of those in the humanities to understand the Second Law of Thermodynamics. While delivering The Rede Lecture in 1959, Snow observed, 'Once or twice I have been provoked and have asked the company how many of them could describe the Second Law of Thermodynamics. The response was cold: it was also negative. Yet I was asking something which is about the scientific equivalent of: "Have you read a work of Shakespeare's?"'²⁸

Yet, 50 years after delivering his lecture, while scientists are still thought to be illiterate if they haven't read Shakespeare, how many experts in the arts would be able to explain the laws of thermodynamics? This is not simple point-scoring between disciplines. Politicians and civil servants tend to be drawn from the fields of economics, politics, history and the arts.²⁹ This could go some way to explain why, on one level, the mainstream political and economic establishment have little comprehension about the finiteness of the planet's resources and the limits to efficiency.

One representative from a conservative economic think tank was questioned on where the resources to fuel infinite economic growth would come from. It was at a public debate in the Dana Centre, part of the Science Museum in London. After thinking for a moment, his answer was confidently asserted, 'We could mine asteroids,' he said.

The First Law

The First Law of Thermodynamics, formalised by nineteenth-century German physicist, Rudolf Clausius, is a generalisation of the universal law of energy conservation.³⁰ The First Law states that within a closed system, energy can neither be created nor destroyed. For example, energy within the Universe is constant, or the amount of energy lost in a steady-state process cannot be greater than the amount of energy gained. Thus, a measure of heat transferred into a system will result in an increase in temperature and in the system's ability to do work.

The Second Law

The Second Law of Thermodynamics applies a direction to the conservation of energy described by the First Law. It says that not all heat input into a system can be converted into useful work. Put simply, transferring heat into work with 100 per cent efficiency is impossible. Some heat will always escape into the surrounding environment as wasted energy. Ultimately, therefore, all energy tends to heat or disorder (entropy) and no transaction of energy from one type to another is completely reversible.

Because the laws of thermodynamics imply that entropy will always increase, Clausius imagined that sometime in the distant future – the universe would eventually fall fate to a 'heat death'. Entropy will have increased to its maximum level and no more work could be done.

As entropy increases – 'free energy' or *exergy* decreases. This describes the maximum useful work obtainable from an energy system at a given state in a specified environment. In other words, it represents the thermodynamic 'quality' of an energy carrier based on the Second Law. For example, electricity has a high degree of exergy and is widely regarded as an efficient carrier of energy. Low-temperature hot water, however, has low exergy and whilst it is also a carrier of energy, can generally only be used for heating purposes.

According to the second law of thermodynamics, order (sometimes called negative-entropy, neg-entropy) can be increased only at the expense of generating more disorder (entropy) elsewhere.³¹ This means importantly that human-created order – the emergence of structured civilisation and latterly that of advanced industrialised society – will also result in large quantities of entropy in/on the surrounding environment.³²

From this, the potential for environmental damage from economic activity becomes clear. Industrial activities cannot continue without energy, nor can they be generated without some environmental impact.

This observation was the basis of Herman Daly's 'steady-state economy' which, building on the work of economist Nicholas Georgescu-Roegen, challenges humanity's failure to notice the entropic nature of the economic process (although, it is more fairly, a specific failure of mainstream economics).^{33,34}

While the Second Law means that energy efficiency in any process can never in reality be 100 per cent, the practical limits of energy efficiency approached in the real world is much lower. This is discussed in more detail later on in the report.

Why the 'unthinkable' must be debated

The meaning of sustainability has been blurred since the flurry of activity that led up to the United Nation's 1992 Earth Summit in Brazil. Today it is applied as much to merely sustaining economic growth as it is to preserving a liveable planet for future generations.

This mainstream view of sustainable development is quite different from definitions of so-called 'strong sustainability' (Box 4). The 'mainstream' view tends to emphasise decoupling economic growth from environmental degradation (including climate change). And, to drive that dynamic it relies heavily on market-based initiatives – the 'ecological modernisation' of the economy, defined by German sociologist Joseph Huber as a twin process of 'ecologising the economy' and 'economising ecology'.³⁵

Ecological modernisation assumes that already existing political, economic and social institutions can adequately deal with environmental problems – focusing, almost exclusively on industrialism, with much less consideration (if any at all) being given to the accumulative process of capitalism, military power or the nation-state system, even though all contribute in different ways to environmental degradation by being instrumental to growth and international competitiveness.³⁶

Policies of environmental or ecological modernisation include: the 'polluter pays' principle, eco-taxes, government purchasing initiatives, consumer education campaigns and instituting voluntary eco-labelling schemes. Such a strategy relies on small acts of individual consumer sovereignty (sustainable consumption) to change the market.³⁷ The growing emphasis on the individual to practice sustainable consumption as a cure-all, however, is awkwardly juxtaposed against the systemic nature of the problems. There is now a growing view and body of evidence that ecological modernisation has not been effective in reducing carbon emissions. In fact, some would argue it has acted in the opposite direction, driving emissions upwards.

Environmental debates, therefore, seem caught between paralysing catastrophe scenarios, and ill-thought-out technological optimism. We are told that either the planet would like to see the back of us, or that we can have the planet and eat it. The truth, as ever, is more complex and interesting.

The point of this report, *Growth isn't possible*, is to remove an obstacle to exploring the possibilities in that more nuanced reality. Mainstream economics is frozen in its one-eyed obsession with growth. Across the political spectrum of governments, pursuing international competitiveness and a rising GDP is still seen as panacea for social, economic and environmental problems. Unfortunately, a combination of the science of climate change, natural resource accounting, economic realities and the laws of physics tell us that this assertion has become quite detached from reality. Our earlier report, *Growth isn't working*, showed that global economic growth is a very inefficient way to reduce poverty, and is becoming even less so.

Why growth isn't working

Between 1990 and 2001, for every \$100 worth of growth in the world's income per person, just \$0.60, down from \$2.20 the previous decade, found its target and contributed to reducing poverty below the \$1-a-day line.³⁸ A single dollar of poverty reduction took \$166 of additional global production and consumption, with all its associated environmental impacts. It created the paradox that ever smaller amounts of poverty reduction amongst the poorest people of the world required ever larger amounts of conspicuous consumption by the rich.

Growth wasn't (and still isn't) working.³⁹ Yet, so deeply engrained is the commitment to growth, that to question it is treated as a challenge to the whole exercise of economics. Nothing could be further from the truth. This report is a companion volume to **nef's** earlier and ongoing research. It is written in the hope that we can begin to look at the fascinating opportunities for economics that lie beyond the doctrine – it could be called dogma – of growth.

One of the few modern economists to have imagined such possibilities in any depth is Herman Daly.⁴⁰ The kind of approach called for in a world constrained by fuzzy but fundamental limits to its biocapacity is one, according to Daly, that is: '... a subtle and complex economics of maintenance, qualitative improvements, sharing frugality, and adaptation to natural limits. It is an economics of better, not bigger'.⁴¹

Box 4. Sustainable development?

Civil servant and environmental economist, Michael Jacobs described six core ideals and themes within sustainable development. These include:⁴²

- The integration of the economy and environment: economic decisions to have regard to their environmental consequences.
- Intergenerational obligation: current decisions and practices to take account of their effect on future generations.
- Social justice: all people have the equal right to an environment in which they can flourish (or have their basic human needs met).
- Environmental protection: conservation of resources and protection of the non-human world.
- Quality of life: a wider definition of human well-being beyond narrowly defined economic prosperity;
- Participation: institutions to be restructured to allow all voices to be heard in decision-making (procedural justice).

The core ideals cover three fields – the environment, economy and society – the three pillars of sustainability. A view of sustainable development that encompasses all three dimensions can be defined as ‘strong sustainability’.

According to Andrew Dobson, Professor of Politics at Keele University, ‘strong sustainability’ will require, ‘radical changes in our relation with the non-human natural world, and in our mode of social and political life’.⁴³

Relying on the wished-for trickle-down of income from global growth as the main economic strategy to meet human needs, maximise well-being and achieve poverty reduction appears ineffective, frequently counter-productive and is in all practical senses, impossible.

Given current, highly unequal patterns of the distribution of benefits from growth, to get everyone in the world onto an income of at least \$3 per day – the level around which income stops having an extreme effect on life expectancy – implies, bizarrely, the need for 15 planets’ worth of resources to sustain the requisite growth. Even then, environmental costs would fall disproportionately, and counter-productively, on the poorest – the very people the growth is meant to benefit.⁴⁴

So, globally, including in relatively rich countries, there is a danger of locking in a self-defeating spiral of over-consumption by those who are already wealthy, justified against achieving marginal increases in wealth amongst the poorest members of society.

Another assault on the doctrine of growth stems from the large but still emerging field of studying life-satisfaction and human well-being. It presents a critique of how, in industrialised countries, patterns of work and rising consumption are promoted and pursued that repeatedly fail to deliver the expected gains in life satisfaction. At the same time, these patterns of (over)work potentially erode current well-being by undermining family relationships and the time needed for personal development.⁴⁵

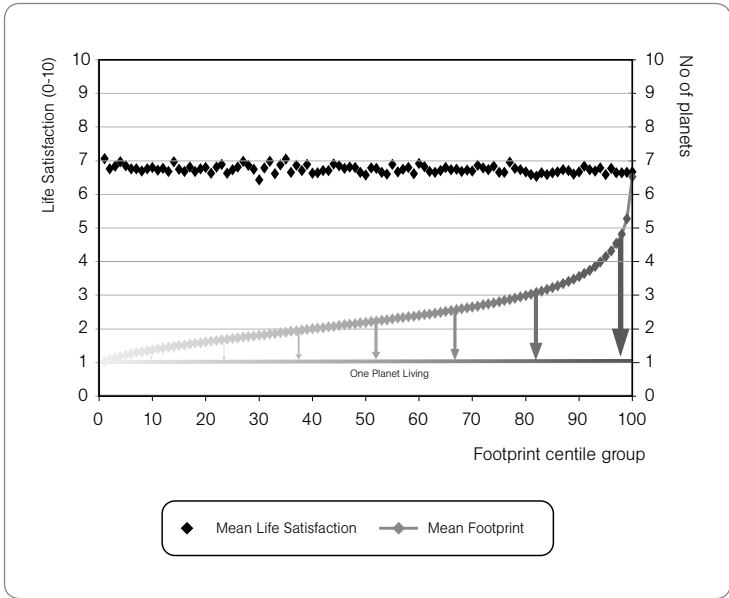
The assumption that by increasing efficiency, whether it is energy efficiency or resource efficiency, will allow us to continue along the same, ever expanding consumption path is wrong. It does, however, allow us to skirt around the bigger issue relating to work-and-spend lifestyles that developed nations have become so accustomed to, and which are unquestioningly assumed to be the correct and best development models for developing nations.

In fact, a growing body of literature shows that once people have enough to meet their basic needs and are able to survive with reasonable comfort, higher levels of consumption do not tend to translate into higher levels of life satisfaction, or well-being.⁴⁶ Instead, people tend to adapt relatively quickly to improvements in their material standard of living, and soon return to their prior level of life satisfaction. This is known as becoming trapped on the 'hedonic treadmill', whereby ever higher levels of consumption are sought in the belief that they will lead to a better life, whilst simultaneously changing expectations leave people in effect having to 'run faster', consuming more, merely to stand still.

National trends in subjective life satisfaction (an important predictor of other hard, quantitative indicators such as health) stay stubbornly flat once a fairly low level of GDP per capita is reached.⁴⁷ And, importantly, only around 10 per cent of the variation in subjective happiness observed in western populations is attributable to differences in actual material circumstances, such as income and possessions.⁴⁸

Figure 1 shows the results of an online survey of life satisfaction and consumption in Europe, gathered by **nef**. The web-based survey contained questions about lifestyle – consumption patterns, diet, health, family history – as well as subjective life satisfaction. Using this data, estimates of footprint and life expectancy could be calculated. Over 35,000 people in Europe completed the survey.

Figure 1: Life satisfaction compared to levels of material consumption in Europe.⁴⁹



The blue line represents the distribution of ecological footprints across the total sample, expressed in terms of the number of planets' worth of resources that would be required if everyone on the planet were to live the same way. To the right end of the distribution are those people with high consumption lifestyles, approaching 'seven planet living'. To the left are those whose lifestyles have the least environmental impact, approaching the planetary fair share 'one planet living'. The arrows depict the nature of the transition that is required both to level and lower the consumption playing field towards equitable and sustainable use of the Earth's resources.

This data represents both a challenge and an opportunity. It is challenging because it shows starkly the extent of European over-use of planetary resources. Not only is the distribution of footprint extremely unequal in this sample, it is also far too high in absolute terms. But, Figure 1 also suggests that well-being has little to do with consumption; which, in turn, allows for the possibility that our collective footprint could be reduced significantly without leading to widespread loss in well-being. As one analyst put it, an initial reduction in energy use of around one-quarter 'would

Box 5. Life rage

*Economic growth is indeed triumphant, but to no point. For material prosperity does not make humans happier: the 'triumph of economic growth' is not a triumph of humanity over material wants; rather it is the triumph of material wants over humanity.*⁵⁰

Professor Richard Layard, London School of Economics

Studies over the past decade, using both qualitative and quantitative methods, reveal levels of anger and moral anxiety about changes in society that were not apparent 30 years ago.⁵¹ Whilst these studies mainly focused on the UK, the USA and Australia, the findings are, to varying degrees, applicable to other high-consuming industrialised nations. In other words, our levels of well-being are being eroded. But why?

Research shows that the strong relationship between life expectancy and income levels-off at a remarkably low level. The influence of rising income on life satisfaction levels-off at higher levels, but not much higher.^{52,53} Life expectancy continues to rise in most countries and this is only partly due to greater wealth; happiness has not increased in recent decades in rich nations, despite on average, people have become much wealthier.⁵⁴

Social epidemiologist, Professor Richard Wilkinson argues in his book *Impact of inequality: how to make sick societies healthier* that poorer nations with lower wealth inequality tend to have higher levels of well-being (physical and mental) than more wealthy but more unequal nations.⁵⁵ For example, life expectancy in rich nations shows a strong correlation with relative equality. His more recent work with co-author Professor Kate Pickett, *The Spirit Level*, makes an even stronger case.⁵⁶ Here they demonstrate that more equal societies almost always do better against a wide range of social and environmental indicators.

In *Impact of inequality* Wilkinson compared various social indicators in Greece to those in the USA. He found that while Greece has almost half the per capita GDP, citizens have a longer life expectancy than the USA. While globally, the USA is the wealthiest nation, it has one of the highest levels inequality and lowest life expectancy in the global North. Furthermore, Wilkinson demonstrates that crime rates are most strongly correlated to a nation's level of inequality, rather than its aggregated wealth. Given this, Wilkinson concludes that the most equal countries tend to have the highest levels of trust and social capital.

As Nicholas Georgescu-Roegen, one of the fathers of ecological economics argues, as we have become caught up in our obsession with consumption and material throughput, we have failed to recognise the 'immaterial flux of the enjoyment of life'.⁵⁷

call for nothing more than a return to levels that prevailed just a decade or no more than a generation ago', adding rhetorically: 'How could one even use the term sacrifice in this connection? Did we live so unbearably 10 or 30 years ago that the return to those consumption levels cannot be even publicly contemplated by serious policymakers?'⁵⁸

Despite this, high-consuming lifestyles seem 'locked-in' by our economic, technological and cultural context, which fails to address equality and instead drives *relative poverty*. As the gap between the 'haves' and 'have-nots' widens, there tends to be a concomitant loss of life satisfaction, sense of community and, ultimately, a rise in social disequilibrium.

For example, in an update to the infamous Whitehall Study led by Professor Michael Marmot at the Department of Epidemiology and Public Health at University College London, researchers found that subjective socio-economic status was a better predictor of health status and decline in health status over time than more objective measures.^{59,60}

This work implies the health impacts of relative poverty are more likely to be determined by an individual's perception of his or her socio-economic status than, beyond a certain level of sufficient consumption, their actual socio-economic circumstances. Therefore perceived socio-economic barriers can act as a barrier to progressive improvements in overall well-being, as the physical and mental well-being of those in the lowest strata is undermined, creating domino effects throughout society.

There are questions to be asked of growth, of its science-based limits, and more generally of its effectiveness today in meeting human needs and maximising well-being. This report suggests that we are reaching the point at which the doctrine of global economic growth as a central policy objective and primary strategy for meeting society's various needs is becoming redundant.

Later in this report we will argue that focussing only on improvements in carbon and energy intensity of the economy, as a strategy to combat climate change, means only that we are buying time, and even then very little. In a best-case scenario, delaying arrival at critical concentrations of greenhouse gases by 10–20 years, and in a worst-case scenario, not delaying at all. So let us first address the question, what is, and what should be accepted as 'safe' levels of greenhouse gases in the atmosphere?

Greenhouse gas emissions and current climate change

The Earth's climate system is currently changing at greater rates and in patterns that are beyond the characteristics of natural variation. The concentration of carbon dioxide (CO₂) in the atmosphere today, the most prevalent anthropogenic greenhouse gas, far exceeds the natural range of 180–300 ppm. The present concentration is the highest during the last 800,000 years and probably during the last 20 million years.^{61,62,63}

In the space of just 250 years, as a result of the Industrial Revolution and changes to land use, such as the growth of cities and the felling of forests, we have released cumulatively more than 1800 gigatonnes (Gt) of CO₂ into the atmosphere.⁶⁴ Global atmospheric concentrations of CO₂ are now a record 390 ppm, almost 40 per cent higher than they were at the beginning of the Industrial Revolution.^{65,66}

The primary source of the increased concentration of CO₂ is unequivocally due to the burning of fossil fuels such as coal, oil, and natural gas.⁶⁷ Annual fossil fuel CO₂ emissions have increased year on year from an average of 23.4 GtCO₂ per year in the 1990s to 30 GtCO₂ per year today. To put this in perspective, the increase in annual emissions over the past 20 years is almost double the total emissions produced by EU27 nations each year.⁶⁸ Changes in land use have also contributed significantly to increasing rates of CO₂ emissions, contributing around 1.5 GtC per year to the atmosphere.

We now release just over 1000 tonnes of CO₂ into the Earth's atmosphere every second.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report – a synthesis of peer-reviewed research on climate change, its causes and effects (including socio-economic consequences) involving over 2500 scientists worldwide – stated that if fossil fuels continued to be burnt at the current rate, global average surface temperatures could rise by 4°C by the end of the century, with an uncertainty range of 2.4–6.4°C.⁶⁹

A more recent study published in the American science journal *Proceedings of the National Academy of Sciences* found that the 'committed' level of warming by the end of the century is 2.4°C (1.4-4.3°C) – if atmospheric concentrations of greenhouse gases are held at 2005 levels. This value is based on past emissions and includes the warming already observed of 0.76°C plus 1.6°C of additional warming which is yet to occur due to the thermal inertia of the climate system and the 'masking' by cooling aerosols.⁷⁰

Although 2008 may have been the coolest year of the current decade, it was still the tenth warmest year since instrumental records began in 1850.⁷¹ While observations actually suggest that global temperature rise has slowed during the last decade, analyses of observations and modelling studies show that this is due to internal climate variability and that the warming trend will resume in the next few years.^{72,73}

One of the studies by atmospheric scientists Professors Kyle Swanson and Anastasios Tsonis ends with the following cautionary note: '...there is no comfort to be gained by having a climate with a significant degree of internal variability, even if it results in a near-term cessation of global warming... If the role of internal variability in the climate system is as large as this analysis would suggest, warming over the 21st century may well be larger than that predicted by the current generation of models'.⁷⁴

Indeed, over the course of 2008 and 2009 numerous scientific papers were published revealing that climate change was far more serious even than reported in the most recent review of the science by the IPCC.^{75,76} The long-term warming trend has had a large impact on mountain glaciers and snow cover worldwide, and also changes in rainfall patterns and intensity, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones. Such changes to the biophysical world are already having harmful impacts on society, which will worsen with time.

As Professor Stefan Rahmstorf of the Potsdam Institute for Climate Impact Research reflected in 2007: 'As climatologists, we're often under fire because of our pessimistic message, and we're accused of overestimating the problem... But I think the evidence points to the opposite – we may have been underestimating it.'⁷⁷ Two years on, at International Scientific Congress on Climate Change in March 2009, Rahmstorf confirmed this view. 'What we are seeing now is that some aspects are worse than expected', he said speaking at a plenary session of the Congress. He continued: 'I'm frustrated, as are many of my colleagues, that 30 years after the US National Academies of Science issued a strong warning on CO₂ warming, the full urgency of this problem hasn't dawned on politicians and the general public.'⁷⁸

Dangerous climate change

Science on its own cannot give us the answer to the question of how much climate change is too much.

Margaret Beckett speaking at the
Avoiding Dangerous Climate Change Conference (February 2005)

Margaret Beckett's comments highlight the ethical and political dilemma of what constitutes a tolerable degree of climate change. Science can tell us what may happen as the temperature rises, but only we can decide what is tolerable and how far climate change should be allowed to go.

The United Nations Framework Convention on Climate Change (UNFCCC) was signed by over 160 countries at the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992, and came into force in 1994. The objective of the Convention was to slow and stabilize climate change by establishing an overall framework for intergovernmental efforts to respond to climate change. It recognises the significance of climate change and the uncertainties associated with future projections. But it also states that despite uncertainties, mitigating action should be taken – namely a 'no regrets' approach. Furthermore, it recognises the responsibility of developed nations to take the lead due to their historical emissions, and therefore responsibility.

The long-term objective of the Convention, outlined in Article 2, is to achieve:

...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.⁷⁹

The burning embers diagram

An important part of the international climate change debate relates to the interpretation of dangerous climate change. This is of growing importance and of particular relevance to post-Kyoto negotiations.

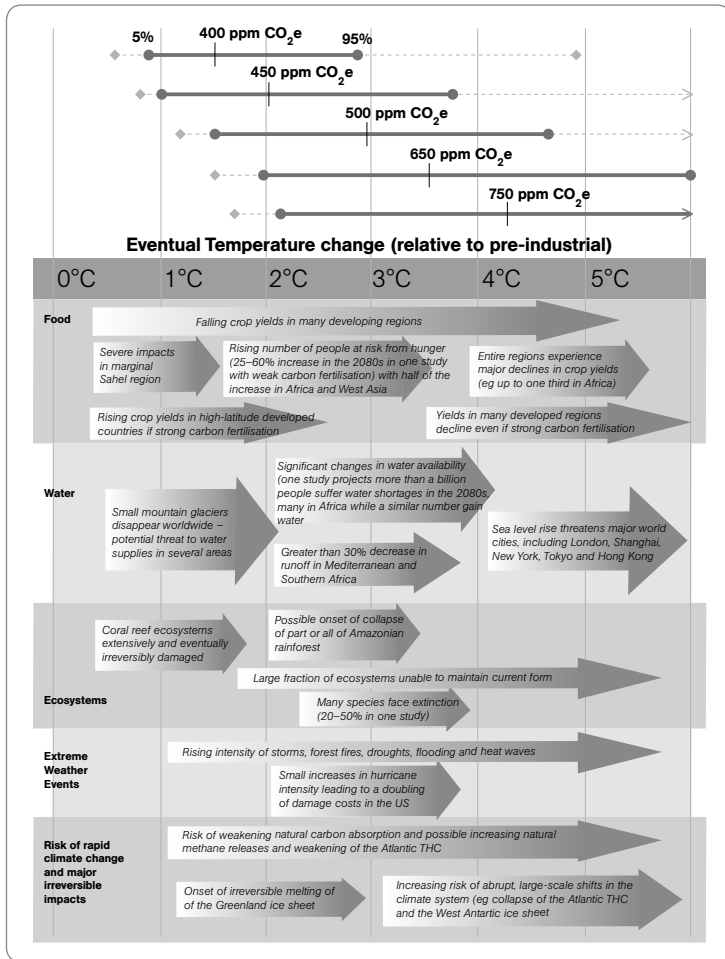
In order to codify what 'dangerous anthropogenic interference' might mean, authors of the Third Assessment Report of the IPCC identified 'five reasons for concern'. These are listed below:⁸⁰

1. Risks to unique and threatened systems – e.g., coral reefs, tropical glaciers, endangered species, unique ecosystems, biodiversity hotspots, small island states and indigenous communities.
2. Risk of extreme weather events – e.g., the frequency and intensity, or consequences of heat waves, floods, droughts, wildfires, or tropical cyclones.
3. Distribution of impacts – some regions, countries and populations are more at risk from climate change than others.
4. Aggregate impacts – e.g., the aggregation of impacts into a single metric such as monetary damages, lives affected or lost.
5. Risks of large scale discontinuities – e.g., tipping points within the climate system such as partial or complete collapse of the West Antarctic or Greenland ice sheet, or collapse/reduction in the North Atlantic Overturning Circulation.

Figure 2, also known as the 'burning embers diagram' is an illustration of the IPCC's five reasons for concern. It shows that the most potentially serious climate change impacts (arrow heads) – expected to be experienced due to a range of equilibrium warming temperatures projected from stabilisation levels between 400 ppm and 750 ppm of carbon dioxide equivalent (CO₂e) – typically occur after only a few degrees of warming.⁸¹

In April 2009, a team of researchers, many of whom were lead authors of the most recent IPCC report, revised the burning embers diagram. While the diagram was rejected from the IPCC's Fourth Assessment Report because the artwork was also thought to be too unnerving, it was later published in the peer-reviewed journal *Proceedings of the National Academy of Sciences*. The updated diagram showed that an even smaller increase in global average surface temperature could lead to significant consequences for all five elements in the 'reasons for concern' framework.⁸²

Figure 2: Burning embers diagram⁸³



The solid horizontal lines indicate the 5–95 per cent range based on climate sensitivity estimates from the IPCC 2001 and a study by one of the UK's leading climate research unit, Hadley Centre study.⁸⁴ The vertical line indicates the mean of the 50th percentile point. The dashed lines show the 5–95 per cent range based on 11 recent studies.⁸⁵ The bottom panel illustrates the range of impacts expected at different levels of warming.

Box 6: Sea-level rise

Rising sea levels will be one of the most significant impacts of climate change over the next century. This is because coastal zones are home to a significant proportion of humanity. These regions often have average population densities three times the global mean density.⁸⁶

Tidal gauge and satellite data shows a global average sea-level rise of 1.8mm per year between 1961 and 2003.⁸⁷ In recent years, however, this rate has increased to around 3.3 ± 0.4 mm per year over the period 1993 to 2006.⁸⁸ This observation is 40 per cent above the IPCC projected best-estimate rise of less than 2mm per year.

The main contribution to rising sea levels has been through thermal expansion of the oceans, but also a contribution from melting land-based ice (e.g. glaciers, and the Greenland and Antarctic ice sheets).

Due to a number of uncertainties about the way that ice-sheets behave, an accurate picture of future sea level rise is difficult to predict. Nevertheless, melt-water from Antarctica, Greenland and small ice caps could lead to a global sea level rise (the mean value of local sea level taken across the ocean) of between 0.75 –2 metres by the end of the century.^{89,90,91}

However, recent research published by NASA's James Hansen and a team of researchers warned that destabilisation of the Greenland ice sheet is possible before global surface temperatures reach 2°C.^{92,93} This could lead to a sea-level rise of seven metres or more. While this rise may occur over a number of centuries, a mechanism of 'albedo-flip' could result in a much more rapid sea-level rise.⁹⁴ The albedo-flip is a key feedback mechanism on large ice sheets, and occurs when snow and ice begin to melt. While snow cover has a high albedo (i.e. reflects back to space most of the sunlight striking it), melting 'wet' ice is darker and absorbs much more sunlight. A proportion of the melt water burrows through the ice sheet and lubricates its base, accelerating the release of icebergs to the ocean.

Such an extreme rise in sea level would have catastrophic implications for humanity. For example one study estimates that currently roughly 410 million people (or about 8 per cent of global population) live within five metres of present high tide.⁹⁵ Allowing for population growth, this figure could well double over the course of the twenty-first century. Densely-populated Nile and Asian 'mega-deltas' may disappear in addition to large areas around the southern North Sea.

Aiming for 2°C

Historically, an increase in equilibrium temperature of Earth's atmosphere by 2°C has been considered a 'safe' level of warming. James Hansen's warning that global temperatures should not be allowed to exceed 1.7°C, however, strongly suggests that a warming of 2°C cannot be described as 'safe'. As Professor Rahmstorf says: 'If we look at all of the impacts, we'll probably decide that two degrees is a compromise number, but it's probably the best we can hope for'.

In 2007, NASA's James Hansen argued in 2007 that temperatures should not go beyond 1.7°C (or 1°C above 2000 temperatures) if we are to avoid aiming to avoid practically irreversible ice sheet and species loss.⁹⁶ For example, collapse of the Greenland ice sheet is more than likely to be triggered by a local warming of 2.7°C, which could correspond to a global mean temperature increase of 2°C or less.^{97,98} The disintegration of the Greenland ice sheet could correspond to a sea-level rise by up to 7m in the next 1000 years, not to mention the positive climate feedback effects due to changes in land-surface reflective properties (see Box 6). This would act to increase the warming as darker surfaces absorb more heat. Coral reef, alpine and Arctic ecosystems will also potentially face irreversible damage below a global average surface temperature rise of 2°C.⁹⁹

In terms of the social impacts of climate change, what is manageable for some is actually catastrophic for others. For example, at the climate change conference in Copenhagen in late 2009, the Alliance of Small Island States – a grouping of 43 of the smallest and most vulnerable countries – rejected the 2°C target. They argued that 1.5°C is a better target, as many of their islands will disappear with warming beyond this point.¹⁰⁰

Climate policy, therefore, needs to redefine what is described as a 'safe' level of warming or redefine its definitions from an acceptable level of warming decided by those who bear the least impact. Additionally, recent research (see Box 10) shows that real temperature outcomes are unlikely to be related to concentrations of greenhouse gases but rather a cumulative carbon budget.^{101,102} In other words, not only is 2°C unsafe, it is unhelpful when defining targets for climate policy.

But, given that a 2°C target is now firmly established within the policy context, it is worth examining what it will mean should this temperature be exceeded. The inter-agency report *Two degrees, one chance* published by Tearfund, Oxfam, Practical Action, Christian Aid states:

Once temperature increase rises above 2°C up to 4 billion people could be experiencing growing water shortages. Agriculture will cease to be viable in parts of the world and millions will be at risk of hunger. The rise in temperature could see 40–60 million more people exposed to malaria in Africa. The threshold for the melting of the Greenland ice sheet is likely to have been passed and sea-level rise will accelerate. Above 2°C lies the greater danger of ‘tipping points’ for soil carbon release and the collapse of the Amazon rainforest.¹⁰³

Abrupt climate change: tipping points in the climate system

The Earth’s geological history is full of examples of abrupt climate change, when the climate system has undergone upheaval, shifting from one relatively stable state to another. Transition to a new state is triggered when a critical threshold is crossed. When this happens, the rate of change becomes determined by the climate system itself, occurring at faster rate than the original forcing. For example, until 6000 years ago the Sahara Desert was covered by vegetation and wetlands. While the transition was driven by subtle and smooth changes in incoming solar radiation, at a critical point there was a regime shift in the rainfall patterns causing the landscape to switch from lush vegetation to desert, at a rate far greater than the original solar forcing.¹⁰⁴

In 2008, Tim Lenton, Professor of Earth System Science and a team of researchers at the University of East Anglia, concluded that because of these critical thresholds in the climate system ‘society may have been lulled into a false sense of security’ by the projections of apparently ‘smooth’ climate change.¹⁰⁵ The research suggested that a variety of *tipping elements* of the climate system, such as the melting of ice sheets or permafrost could reach their critical point (tipping point) within this century under current emission trajectories. Tipping elements describe subsystems of the Earth’s system that are at least sub-continental in scale and can be switched – under certain circumstances – into a qualitatively different state by small perturbations. The tipping point is the corresponding critical point.

Tipping elements identified by the study include: collapse of the Greenland ice sheet; drying of the Amazon rainforest; collapse of the West Antarctic ice sheet; dieback of Boreal forests; greening of the Sahara/Sahel due to a shift in the West African monsoon regime; collapse of the North Atlantic ocean circulation; and changes to the El Niño–Southern Oscillation amplitude.

Whether or not these highly unpredictable factors are made part of decision-making is a political choice. But, given the existence of tipping points in the climate system, it is hard to reconcile the assumption that we may be able to stabilise the climate or even CO₂ concentrations once a certain level of threshold of temperature or concentration of CO₂ is reached. But, the authors of the assessment identified a significant gap in research into the potential of tipping elements in human socio-economic systems, especially into whether and how a rapid societal transition towards sustainability could be triggered.¹⁰⁶

If the impacts of climate change are non-linear then our response both in mitigating against and adapting to climate change also has to be non-linear.

Box 7. Time is running out¹⁰⁷

In August 2008 **nef** calculated that 100 months from 1 August 2008, atmospheric concentrations of greenhouse gases will begin to exceed a point whereby it is no longer *likely* we will be able to avert potentially irreversible climate change. 'Likely' in this context refers to the definition of risk used by the IPCC to mean that, at that particular level of greenhouse gas concentration, there is only a 66–90 per cent chance of global average surface temperatures stabilising at 2°C above pre-industrial levels.

In December 2007, the likely CO₂e concentration is estimated to be just under 377ppm, based on a CO₂ concentration of 383 ppm. This seemingly counter-intuitive measure is explained by the proper inclusion in the CO₂e figure of all emissions effecting radiative forcing – in other words, both those with cooling and warming effects.

If stabilisation occurs at 400 ppm, there is a 10–34 per cent chance of overshooting a 2°C warming. Beyond this point, the probability of stabilising global surface temperatures at less than 2°C decreases. It would seem that if policy-makers are at all serious about avoiding dangerous climate change at a threshold of 2°C or less, emissions need to be reduced significantly.

What is the risk of overshooting 2°C under various stabilisation scenarios?

*We wouldn't fly in a plane that had more than a 1 per cent chance of crashing. We should be at least as careful with the planet. Current climate policies provide us with far less than a 99 per cent chance of avoiding catastrophic climate change.*¹⁰⁸

Paul Sutton, Carbon Equity

When the Kyoto Protocol was established in 1997, the best scientific understanding implied that a 50 per cent reduction in emissions below 1990 levels by 2050 would be sufficient to avoid dangerous climate change. Thirteen years on, the understanding of what constitutes safe climate change has improved significantly. Now, there is a growing consensus that at least an 80 per cent reduction in CO₂ emissions below 1990 levels will be required by 2050 globally if we are to have a greater than 60 per cent chance of not exceeding 2°C.¹⁰⁹ A recent analysis by the Tyndall Centre for Climate Change Research demonstrated what this means for the UK. Incorporating all sectors of the economy, the UK is required to reduce its carbon dioxide emissions by some 70 per cent by 2030, and around 90 per cent by 2050.¹¹⁰

Not only is the safe level of temperature rise misleading as described earlier, a number of assessments exploring the probability of exceeding various temperature thresholds have been published. These studies demonstrate that the stabilisation of atmospheric concentrations of greenhouse gases at anything above 400 ppm is too high to avoid a temperature rise of 2°C.^{111,112}

Research led by Malte Meinhausen, a climate modeller based at the Potsdam Institute for Climate Impact Research in Germany, has shown that stabilisation of greenhouse gas concentrations (defined as CO₂e) at 550 ppm is accompanied by the risk of overshooting 2°C warming by 68–99 per cent.¹¹³ According to the IPCC, this is defined as 'likely' to 'very likely'.¹¹⁴ Meinhausen's work also suggests that only by stabilising emissions at 400 ppm is it 'likely' that the climate will stabilise at 2°C.

In early 2009, however, James Hansen and colleagues at Columbia University contended that current atmospheric concentrations of CO₂ need to be reduced to 350 ppm.¹¹⁵ Hansen's analysis for the first time used a climate sensitivity parameter (temperature change due to an instant doubling of CO₂) that included slower surface albedo feedbacks.

Traditionally, the climate sensitivity parameter only includes fast-feedbacks (i.e. changes to water vapour, clouds and sea-ice) whilst keeping slow changing planetary surface conditions constant (i.e., forests and ice sheets). In addition, long-lived non-CO₂ forcings (other gases and aerosols) are also kept constant over time. It is worth noting, to avoid any confusion, that Hansen and his team were specifically referring to CO₂ only – not CO₂e which also includes non-CO₂ forcings (current atmospheric concentrations of CO₂ are currently at 390 ppm).

The paper concluded with the harrowing warning: 'If humanity wishes to preserve a planet similar to that on which civilization developed and to which life on Earth is adapted, paleoclimate evidence and ongoing climate change suggest that CO₂ will need to be reduced from its current 385 ppm to at most 350 ppm, but likely less than that.'¹¹⁶

Questioning climate policy assumptions

Certain assumptions underlie scenarios for the future stabilisation of greenhouse gas emissions and of their accumulation in the atmosphere. These include that historical rates for both energy efficiency improvements and declining energy intensity will continue and accelerate into the future. In turn, it is assumed that these will result in an absolute decrease in energy consumption. Yet, these assumptions are hugely dependent on three questions that are not so much unanswered, as barely even asked;

1. Is the stabilisation of greenhouse gases through long-term targets the most effective response to climate change?
2. What are the theoretical and practical limits to energy efficiency of the economy?
3. Do increases in energy efficiency actually result in decreases in the demand for energy services?

Under this questioning, current climate change policies appear seriously flawed, worsening the prognosis for future climate change and our ability to deal with it.

For example, there are theoretical limits to efficiency governed by the laws of thermodynamics. There are practical limits to efficiency, relating to economic, social and political barriers, and the speed at which we can replace current energy systems.

Observations in the real world suggest that increases in energy efficiency can have perverse consequences, resulting in rises in the demand for energy services – the so called 'rebound effect' (see Box 8).

Technological optimists believe that technical innovations will reduce the demand for energy.¹¹⁷ But, in fact, technological improvements have tended to push demand for high levels of 'service use' and greater consumption. The history of fuel efficiency in cars is one such example (see Box 8).^{118,119}

Before these questions are addressed, it is necessary to be clear about what is meant by energy efficiency, energy intensity and 'carbon intensity'. All three terms are described in more detail below, but fundamentally, they all represent ratios. This means they place more emphasis on outputs, rather than inputs. And, as long as the growth rate in consumption of the input increases at a greater rate than efficiency (intensity) increases (decreases) any improvements to the system are effectively 'eaten up'. In other words, no absolute reduction to energy consumption or carbon (in the case of carbon intensity) would be observed.

For example, at the global level, even if technological energy efficiency and the uptake of new, more efficient devices increased by 50 per cent over the next 20–30 years with GDP rising at a conservative 2.5 per cent, within 25 years, we'd be back where we are now.^{120,121,122}

Box. 8: The rebound effect

It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth.

William Stanley Jevons (1865)¹²³

There is no evidence that using energy more efficiently reduces the demand for it.

Brookes (1990)¹²⁴

Despite the recognition that consumption levels need to decline in developed nations, governments and businesses are reluctant to address the restriction of consumption. Yet, without limits to consumption, improvements in efficiency are often offset by the 'rebound effect'.¹²⁵

For example, a recent report published by the European Commission's Joint Research Centre (JRC) showed an increase in energy use across all sectors – residential, service and industry – in recent years, despite improvement in energy efficiency.¹²⁶ For example, in the domestic sector while new measures have led to some improvements, particularly in the case of 'white goods' (e.g. refrigerators, washing machines, dishwashers), the increasing use of these products and other household appliances, such as tumble driers, air conditioning and personal computers, has more than offset savings.

The 'rebound effect' was an observation made by William Stanley Jevons in his book *The Coal Question*, published in 1865.¹²⁷ Here, Jevons contended that although technological advancement improves the overall efficiency (*E*) with which a resource is used, efficiency gains *rebound* or even *backfire*, causing higher production and consumption rather than stabilisation or reduction. Since improvements generally reduce the cost of energy per unit, economic theory predicts that this has the effect of triggering an overall increase in consumption.

If a car, for instance, can drive more kilometres on a litre of petrol, the fuel costs per kilometre fall, and so will the total costs per kilometre. The price signal acts to increase consumption and, thus, part of the efficiency gains is lost.

One area where the rebound effect is prominent is domestic energy consumption. An analysis of energy consumption before and after installation of energy savings

measures found that only half of the efficiency gains translate into actual reductions in carbon emissions.¹²⁸ This is supported by more recent analysis of the effectiveness of England's Home Energy Efficiency Scheme (Warm Front). While there are appreciable benefits in terms of use of living space, comfort, quality of life, physical and mental well-being, the analysis found that there was little evidence of lower heating bills.¹²⁹ This has also been observed in Northern Ireland.¹³⁰ In other words, improvements in energy efficiency are offset by increased levels of thermal comfort.

An more in-depth economy-wide assessment of the rebound effect carried out on behalf of the UK Energy Research Council in 2007 found that rebound effects are not exclusive to domestic energy consumption.¹³¹ They can be both direct (e.g., driving further in a fuel-efficient car) and indirect (e.g., spending the money saved on heating on an overseas holiday). Findings from the research suggest that while direct rebound effects may be small – less than 30 per cent for households for example, much less is known about indirect effects. Additionally, the study suggests that in some cases, particularly where energy efficiency significantly decreases the cost of production of energy intensive goods, rebounds may be larger.

A further rebound effect is caused by 'time-saving devices'.¹³² With the current work-and-spend-lifestyle implicit to industrialised societies, there is an increase in the demand for time-saving products. Although these devices save time, they also tend to require more energy, for example, faster modes of transport.

How large is the rebound effect?

How much energy savings are eaten up by the rebound effect is surrounded by lively debate. Estimates range from almost nothing in the energy services¹³³ to being of sufficient strength to completely offset any energy efficient savings.^{134,135} There are a number of empirical analyses, however, that suggest that the rebound effect may be real and significant (Table 2).¹³⁶

The majority of work investigating the rebound effect has focused on a few goods and services.¹³⁷ However, the few studies that explore the macroeconomic impact of the rebound effect, find it to be significant. For example, using a general equilibrium model, one study by environmental economist Toyooki Washida

Table 2. Summary of empirical evidence for rebound effects¹³⁸

Sector	End use	Size of rebound effect
Residential	Space heating	10–30%
Residential	Space cooling	0–50%
Residential	Water heating	<10–40%
Residential	Lighting	5–12%
Residential	Appliances	0%
Residential	Automobiles	10–30%
Business	Lighting	0–2%
Business	Process uses	0–20%

assessed the Japanese Economy.¹³⁹ On testing a variety of levels of CO₂ tax, the rebound effect was found to be significant (between 35–70 per cent of the efficiency savings).

Policy implications

The policy implications of the rebound effect are that energy/carbon needs to be priced so the price remains relatively constant while efficiencies improve. Surprisingly, however, rebound effects have often been neglected by both experts and policymakers. For example, they do not feature in the recent Stern and IPCC reports or in the UK Government's Energy White Paper.¹⁴⁰ According to Steve Sorrell, a senior fellow at the Science and Policy Research Unit at the University of Sussex: 'This is a mistake. If we do not make sufficient allowance for rebound effects, we will overestimate the contribution that energy efficiency can make to reducing carbon emissions. This is especially important given that the Climate Change Bill (now Act) proposes legally binding commitments to meet carbon emissions reduction targets.'¹⁴¹

Box 9. The history of fuel efficiency in cars

Technological improvements in fuel efficiency have largely been offset by traffic growth and low occupancy rates. The increase in traffic has affected the ability of drivers to utilise the maximum vehicle efficiency speed, but the increase in traffic also means that demand for safer vehicles has significantly increased the weight of vehicles. This phenomenon is termed ‘cocooning’, and is due to the fact that we now spend so much time in cars. Vehicles now have more and more gadgets to provide greater levels of comfort as people spend more and more time sitting in traffic jams or travelling further distances. This has had the effect of increasing the weight of the vehicle and also the energy required to power the gadgets in them.

Table 3 compares the fuel consumption of the Volkswagen Golf (a reference case for all compact family cars) over the period 1975–2003. Since 1975, fuel consumption has improved by a measly 5 per cent. When compared with the weight of the vehicle, it is clear that the reason for the modest improvements in fuel consumption is due to a greater than 50 per cent increase in the weight of the vehicle.¹⁴²

Table 3. Fuel consumption of the Volkswagen Golf 1975–2003.

Model	Year	Engine size (litre)/ horsepower	Fuel consumption (l/10km)	Weight (kg)
Golf LS	1975	1.6/70	0.70	780
Golf CL	1985	1.6/75	0.78	870
Golf CL	1995	1.6/75	0.72	1060
Golf Edition	2003	1.4/75	0.66	1174

Are long-term stabilisation targets the correct policy response?

Recent modelling studies suggest that stabilisation of greenhouse gas emissions is far from the most effective policy response to climate change. For example, using a coupled climate carbon-cycle model, one study found that from a suite of nine IPCC stabilisation scenarios, eight showed that temperatures did not appear to stabilise over

the next several centuries, but rather continued to increase well beyond the point of CO₂ stabilisation at around 2400.¹⁴³ The continuation of temperature increase beyond atmospheric CO₂ stabilisation is due to the long thermal memory (i.e., long-term changes in planetary albedo, due to loss of ice caps, changes in cloud cover, etc.) and equilibration time of the climate system.¹⁴⁴

Given this, many are now calling for a policy response of a 'peak and decline', not just in carbon emissions but also atmospheric concentrations of CO₂. The faster and

Box 10. The trillionth tonne

Due to uncertainties in the carbon-cycle (see Box 8), the final equilibrium temperature change associated with a given stabilisation concentration of greenhouse gases is poorly understood. In order to address this uncertainty, a number of studies have begun to quantify cumulative greenhouse gas emissions that would limit warming to below 2°C.¹⁴⁵

Meinshausen, also the lead author of one of the studies, found that in order to stand a 75 per cent chance of keeping temperatures below 2°C, the world has to limit the cumulative emissions of *all* greenhouse gases to approximately 1.5 trillion tonnes of CO₂e. To reduce the risk by another 5 per cent, this means capping total emissions to just over 1 trillion tonnes of CO₂e.¹⁴⁶

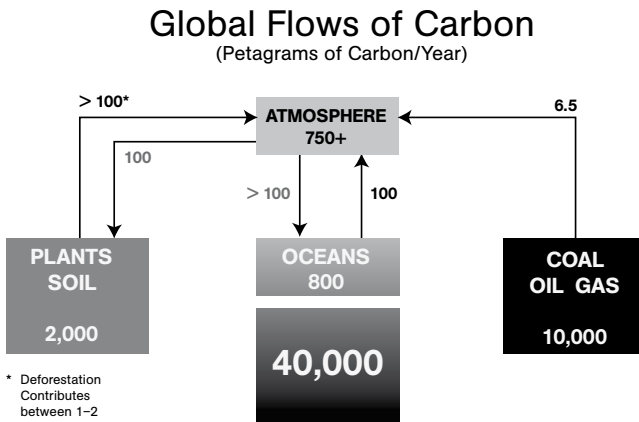
Myles Allen, Head of the Climate Dynamics group at University of Oxford's Atmospheric, Oceanic and Planetary Physics Department and lead author of another study comes to similar a conclusion. Allen and his colleagues argue that if humans can limit cumulative emissions of carbon to one trillion tonnes of carbon, there is a good chance not exceeding the 2°C. They estimate that we could follow our current emissions pathway for another 40 years, and then would have stop emitting carbon in to the atmosphere altogether.¹⁴⁷

But, this doesn't mean we've got 40 years; far from it. Meinshausen argues that if emissions are still 25 per cent above 2000 levels in 2020, the risk of exceeding 2°C shifts to more likely than not.¹⁴⁸ That's a reduction in global emissions by 2.5 per cent year on year, starting now. Given that emissions are currently growing at approximately 3.5 per cent per year – this represents a phenomenal challenge, and requires unprecedented action.

Box 11. Global carbon-cycle feedbacks

Less than half of fossil fuel carbon emitted remains in the atmosphere. For the period 2000–2005, the fraction of total anthropogenic CO₂ emissions remaining in the atmosphere has been around 0.48. This is because over half has been sequestered by the global carbon cycle.¹⁴⁹ This fraction, however, has increased slowly with time, implying that there is a weakening of the carbon sinks relative to emissions.¹⁵⁰ A very real and immediate concern is what effect both increasing concentrations of CO₂ in the atmosphere and the subsequent temperature affect will have on the global carbon cycle.

Figure 3: Global flows of Carbon¹⁵¹



Graphic by Michael Ernst & Skee Houghton
The Woods Hole Research Center

Weakening of terrestrial and oceanic sinks could accelerate climate change and result in a greater warming. This will therefore mean even lower levels of anthropogenic greenhouse gas emissions than currently imagined may be necessary to achieve a given stabilisation target.

Positive terrestrial carbon-cycle feedbacks result from a combination of increased soil respiration and decreased vegetation production due to climate change. Positive oceanic carbon-cycle feedbacks, however, result from decreased CO₂ solubility with increasing ocean temperature, as well as changes in ocean buffering capacity, ocean circulation and the solubility pump (the mechanism that draws atmospheric CO₂ into the ocean's interior). The net effect is to amplify the growth of atmospheric CO₂.

Observations suggest that the carbon sinks may already be weakening. For example a paper published in the journal *Science* in 2007 found evidence to suggest that the Southern Ocean sink of CO₂ had weakened over the period 1981–2004.¹⁵² This is significant because the Southern Ocean is one of the largest carbon sinks, absorbing 15 per cent of all carbon emissions. The study found that the proportion of CO₂ absorbed by the Southern Ocean had remained the same for 24 years, even though emissions have increased by around 40 per cent during the same period.

The Southern Ocean was absorbing 5–30 per cent less CO₂ than previously thought, and it is believed that a strengthening of Southern Ocean winds caused by man-made climate change has reduced the efficiency of transportation of CO₂ to the deep ocean. Rather than CO₂ finding its way into the deep ocean, where it stays, it is being released by the increase in ocean mixing caused by strengthening winds. Worryingly, climate models did not predict this would happen for another 40 years.¹⁵³

Whilst carbon-cycle feedbacks have been recognised for a number of years, it is only recently, with the aid of coupled carbon-cycle climate models, that these CO₂ feedbacks have been quantified. A recent study that compared a number of different carbon-cycle climate models suggested that by the end of the century, the additional concentration of CO₂ in the atmosphere due to carbon-cycle feedbacks could be between 20 and 200 ppm, with the majority of the models lying between 50 and 100 ppm.¹⁵⁴

Recent real time observations suggest an already increased rate of atmospheric CO₂ growth and reduced efficiency of ocean sinks, leads us to fear that the additional CO₂ input into the atmosphere is more likely to reside near the uppermost figure.

further that greenhouse gas concentrations can be lowered below their peak, the lower the maximum temperature reached will be.

The latest IPCC report also acknowledges that anthropogenic warming and sea-level rise could continue for up to 1000 years after stabilisation of atmospheric greenhouse gas concentrations.¹⁵⁵ This, of course, makes the very notion of stabilisation of the climate untenable due to the complex push-pull relationship between temperature and CO₂ concentration.

The relationship between economics, growth and carbon emissions

There was a time when the relationship between carbon emissions and economic growth seemed so simple. Until recently, it was often argued that the relationship between income and CO₂ emissions followed the Environmental Kuznets Curve (EKC) model. The EKC evolved from Simon Kuznets's original thesis on economic growth and income inequality.¹⁵⁶ Kuznets postulated that with economic growth, income inequality first increases over time, and then at a certain point begins to reverse. In theory, then, the relationship between economic growth and income inequality placed on a graph takes on the shape of an inverted-U.

In environmental economics, the EKC proposes a relationship between environmental pollution and economic activity.¹⁵⁷ The theory again suggests an early rise in pollution that later reverses its relationship with growth. Several attempts have been made to determine whether the EKC paradigm can be applied to per capita emissions of CO₂ in the form of a Carbon Kuznets Curve.¹⁵⁸

Some early literature on the subject does suggest that there is a relationship between per capita income in a country and the per capita or gross emissions in the country.^{159,160} There is now unequivocal evidence, however, that in the case of carbon emissions, the EKC simply represents idiosyncratic correlations and holds no predictive power.¹⁶¹

For example a recent study published in the journal *Proceedings of the National Academy of Sciences* found that income was the biggest driver of ever increasing emissions.¹⁶² Of nine regions, which included developed regions such as the USA, Europe, Japan, and developing regions such as China, India, all showed a strong correlation of increasing emissions and income.

The problems of directly applying the EKC paradigm to greenhouse gases are twofold.

First, key greenhouse gases have a long atmospheric lifetime¹⁶³ compared to other environmental pollutants, such as particulates. Their long atmospheric lifetime means that their environmental impact is transboundary, i.e., their effect on the climate is not restricted to the region within which they are produced. Given the asymmetries of the stages of economic development between nations, in principle the EKC model for global climate change cannot work, and the connection between control of domestic emissions in higher-income countries and the benefits to their citizens is very weak. Calculations based on direct national emissions are also misleading because they fail to account for the 'embedded' carbon of goods manufacture abroad and consumed domestically. For example, the effect of much of Britain's heavy industry and manufacturing having been 'outsourced' to less wealthy countries creates the impression that Britain pollutes less, now that it is richer. In fact, the pollution has largely been outsourced too. It still exists, but not on Britain's official inventory of emissions (see Box 12).

Second, we are constrained by the arrow of time. There is clear evidence to suggest that both developed and developing economies would begin the decline on the inverted-U curve well beyond concentrations of greenhouse gases that are classed as safe.¹⁶⁴ In other words, by the time we got to the less polluting slope of the curve, we would already have gone over the cliff of irreversible global warming; it would be too late to be green.

Box 12. Carbon laundering: the real driver of falling carbon and energy intensity in developed nations

As economies develop, historically there is a move away from heavy industry towards service-driven economies that are less energy intensive, so-called 'post-industrialism'. The crude method of national reporting of carbon emissions, and therefore carbon intensity, further reinforces the impression of declining environmental impact.

Yet, in fact, nothing could be further from the truth. In a global economy, it's not just about how the majority of a nation's population earn their living, it's also about how they consume. High incomes have conventionally led to high consumption. So rather than declining carbon emissions, high end-service economies actually increase global energy and material throughput, outsourcing production to other nations rather than decarbonising and dematerialising the economy.

In 2001, over five billion tonnes of CO₂ were embodied in the international trade of goods and services, most of which flowed from developing nations (non-Annex 1 nations of the UNFCCC) to developed nations (Annex 1 nations of the UNFCCC) – i.e., five billion tonnes excluded from developed nations emissions inventories.¹⁶⁵ This is greater than total annual CO₂ emissions from all EU25 nations combined.¹⁶⁶ This means, in effect, the economies of countries like the UK and the USA are 'laundering carbon' to offshore carbon inventories.

This was illustrated by the report from City firm, Henderson Global Investors, *The Carbon 100*.¹⁶⁷ It suggested that the UK may be responsible for more than the 'official' 2.13 per cent responsibility often claimed by politicians.

The Carbon 100 suggested that the UK was actually responsible for between six to eight times more than this (around 12–15 per cent). Tracing the worldwide activities of the UK's leading companies listed on the UK stock exchange paints a more accurate picture of the UK's real emissions responsibility.

While establishing the 'embodied emissions' of trade is notoriously difficult, a recent study published by researchers from Lancaster University's Environment Centre explored the carbon embodied within trade flows between the UK and China.¹⁶⁸ The study showed that imports from China to the UK were embodied

with 555 million tonnes of CO₂ in 2004. Put another way – the carbon embodied in trade reduces the *apparent* CO₂ emissions of UK consumers by 11 per cent, but increases the *real* carbon footprint of UK consumers by 19 per cent and global emissions by 0.4 per cent. This is due to the carbon inefficiencies of Chinese industrial processes compared to those in the UK. Furthermore, the study estimated that the shipping of goods from China to the UK in 2004 resulted in the emission of perhaps a further 10 MtCO₂. This estimate falls towards the high end of earlier estimates for embodied carbon for *all* of the UK's trade partners. It also means that the UK's progress towards its Kyoto emission targets of 12.5 per cent below 1990 levels vanishes into the global economic atmosphere.

This suggests that carbon or energy intensity is an indicator that is grossly misleading at the national level. As a country moves towards post-industrialism, the goods demanded by the high-consumption society are simply produced elsewhere, resulting in a displacement of emissions. A more accurate indicator of changes in domestic emissions would be on a per capita basis based on the average individual ecological/carbon footprint. See for example **nef's** report *Chinadependence: The second UK Interdependence Day report*.¹⁶⁹

Energy efficiency, energy intensity and carbon intensity

There are two types of energy efficiency improvements. The first relates to the development or exploration of more sustainable conversion technologies ranging from renewable technology, to improved efficiency of electricity generation. This will be referred to as supply-side efficiency or ϵ_{ss} .

The second relates to the improvement in energy efficiency of demand-side applications or end-use efficiency $-\epsilon_{cu}$. For example, ϵ_{cu} can be improved by increasing the efficiency of light bulbs, fridges, televisions, and so on.

The overall efficiency (E) of converting primary energy into GDP can therefore be defined as the product of ϵ_{ss} and end-use efficiency ϵ_{cu} . Energy intensity (energy use per unit of GDP) is the inverse of E, this is shown in Equation 1.

Equation 1

$$\begin{aligned} E &= \epsilon_{ss} \times \epsilon_{cu} \\ &= (\text{useful energy/primary energy}) \times (\text{GDP/useful energy}) \\ &= (\text{GDP/primary energy}) \\ &= 1 / \text{Energy intensity of the economy} \end{aligned}$$

Box 13. The Kaya Identity

The Kaya Identity, developed by the Japanese energy economist Yoichi Kaya plays a core role in the development of future emissions scenarios in the IPCC Special Report on Emissions Scenarios (SRES).^{170,171} It shows that total (anthropogenic) emission levels depend on the product of four variables: population, Gross Domestic Product (GDP) per capita, energy use per unit of GDP (energy intensity) and emissions per unit of energy consumed (carbon intensity of energy). The Kaya Identity is shown in Equation 2. It has, been adapted to take into account natural carbon sinks.¹⁷²

Equation 2

$$\text{Net F} = P \left(\frac{G}{P} \right) \left(\frac{E}{G} \right) \left(\frac{F}{E} \right) - S = P_{gef} - S$$

Where:

Net F is the magnitude of net carbon emissions to the atmosphere

F is global CO₂ emissions from human sources

P is global population

G is world GDP and $g = \frac{G}{P}$ is global per-capita GDP,

E is global primary energy consumption and $e = \frac{E}{G}$ is the energy intensity of world GDP,

and $f = \frac{F}{E}$ is the carbon intensity of energy,

S is the natural (or induced) carbon sink.

Climate policy so far has dealt with the second half of the equation – energy intensity of the economy and carbon intensity of energy. For the former, the ratio is expected to decline over time through improvements in efficiency of both supply and demand. Carbon intensity (f) of energy relates to improvements in efficiency of carbon-based energy supply and decarbonisation of the energy

supply through diffusion of renewable energy technology (wind, hydro, solar, geothermal and biomass) nuclear fission.

In terms of population growth, it is noteworthy that fertility rates in the developed world have fallen dramatically in recent decades.¹⁷³ In terms of both social justice and effectiveness, the education of women is the only viable option for the long-term stabilisation of population growth. This, in turn, is dependent on the progress of human development. Nevertheless, by 2050, the global population is expected to reach nine billion.¹⁷⁴ Economic growth, however, defined by changes in *g* remains, by and large and as discussed earlier in this report; unchallenged.

Recent evidence suggests that the surge in emissions growth is primarily due to increases in economic activity. The growth rate of CO₂ emissions includes carbon-cycle feedbacks (see Box 11) as well as direct anthropogenic emissions. Of the 3.3 per cent average annual growth rate of emissions between 2000 and 2006, 18 ± 15 per cent of the annual growth rate is due to carbon-cycle feedbacks, while 17 ± 6 per cent is due to the increasing carbon intensity of the global economy (ratio of carbon per unit of economic activity).¹⁷⁵ The remaining 65 ± 16 per cent is due to the increase in the global economic activity.

While it is often argued that technological innovation could in theory improve resource and energy efficiency and lead to decarbonisation of the economy, recent evidence challenges this view. This is discussed later on in this report.

Energy intensity, the amount of primary energy required to generate economic activity (GDP), is a standard for energy use per unit of productivity. While *carbon intensity* refers to the carbon produced for each unit of productivity (see Box 13 on the Kaya Identity). Since carbon emissions and energy consumption are currently so strongly coupled, at present the two terms can effectively be viewed as roughly analogous.¹⁷⁶

Logically, therefore, energy intensity improvements will only reduce emissions if improvements are made at a greater rate than increases in GDP. For example, the International Energy Agency's (IEA) World Energy Outlook 2009 projects increases in global average economic growth by 3.1 per cent per annum between 2007 and 2030. In order to observe absolute reductions in carbon emissions of 1 per cent per year, the carbon intensity of the economy would need to improve by 4.1 per cent per year assuming energy intensity remains the same.¹⁷⁷

Historically, global carbon intensity of energy has declined at a average rate of around 1.3 per cent per year since the mid-1800s.¹⁷⁸ However, disaggregating these data over the past 40 years gives a more much more detailed picture (see Table 4).

Since 1971 global carbon intensity of the energy has fallen, on average fallen by just 0.15 per cent each year, with a maximum annual decline of 0.41 per cent between 1980 and 2000. However, in recent years the carbon intensity of energy has increased at a rate of 0.33 per cent between 2000–2007. This increase in carbon intensity of energy is due to the increased use of coal in recent years. While coal use grew less rapidly than all other sources of energy between 1971–2002 over the past four years this trend has been reversed. Coal use is now growing by 6.1 per cent each year, more than double the rate of all other energy sources.¹⁷⁹ This rise in carbon intensity of energy has more than offset the small improvements in energy intensity of the economy – bringing improvements to carbon intensity of the economy to a standstill and causing total carbon emissions to soar.

Even in developed nations, carbon intensity of the economy and energy have never managed to reach the levels required to stop total carbon emissions rising year on year. Table 5 shows changes in carbon intensity in the United States. Since the 1950s, carbon intensity in the USA declined at an average rate of around 1.6 per cent per year, with a maximum annual decline in carbon intensity of 2.7 per cent between 1980 and 1990. Current rates of carbon intensity fall are now around 1.6 per cent annually.

At a time where never before has there been so much financial and intellectual capital directed towards innovation to improve the carbon and energy intensity of the

Table 4: Change in global carbon intensity¹⁸⁰

Time period	Average rate of change (negative numbers imply a fall, positive numbers imply a rise)			
	Carbon intensity of the economy (F/GDP)	Energy intensity of the economy (E/GDP)	Carbon intensity of energy (F/E)	Total carbon emissions
1970–1980	-0.79%	-0.65%	-0.16%	2.25%
1980–1990	-1.32%	-0.83%	-0.41%	1.11%
1990–2000	-1.44%	-1.17%	0.18%	0.89%
2000–2007	-0.03%	-0.40%	0.37%	3%

Box 14: The UK: Leading by example?

The UK 'dash for gas' was largely responsible for the relative ease with which the UK reached its Kyoto Protocol targets. For example, the Royal Commission for Environmental Pollution (RCEP) states that the UK's emission reductions are 'largely fortuitous'.¹⁸¹ The 'dash for gas' was due to the rapid shift in electricity generation from coal to gas in the early 1990s.¹⁸² This was an unintended consequence of the Conservative government's liberalisation of the energy market. Although this has been supplemented by changes to industrial processes, waste management and the outsourcing of production to developing nations such as China and India (see Box 12).¹⁸³

A Defra (Department for the Environment, Food and Rural Affairs) spokeswoman said the UK had already beaten its 2012 emissions target of 12.5 per cent under the Kyoto protocol and that the figures for 2005 showed a reduction of 15.3 per cent on 1990 levels. 'The action we have taken to cut our greenhouse gas emissions at the same time as maintaining economic growth makes us an exemplar,' she said.¹⁸⁴ In reality, the majority of the UK's emissions reductions have simply been achieved through this fuel switch (and outsourcing of production).

For example, simply by displacing 1400GW of base load coal-fired power stations with 1400GW of energy efficient combined cycle gas turbine (CCGT) power stations could save approximately 1 billion tonnes of carbon (3.67 billion tonnes of CO₂) per year.¹⁸⁵ Indeed, this has been proposed as one such method of reducing global emissions. But, as we shall see later, like its fuel-cousin oil, natural gas too is facing production limits.

The UK Climate Change Programme (2006) suggests that 25 per cent of emissions reductions in the UK were due to fuel switching in 1990s from coal to gas. A further 35 per cent of reductions were thought to be due to energy efficiency (but could equally be due to outsourcing of production), and a further 30 per cent of reductions were due to the reduction of non-CO₂ greenhouse gases (comparatively less reduction compared to CO₂ due to the higher global warming potential of, for example, methane, nitrous oxide and fluorinated gases).

Table 5: Change in carbon intensity in the United States¹⁸⁶

Time period	Average rate of change (negative numbers imply a fall, positive numbers imply a rise)			
	Carbon intensity of the economy (F/GDP)	Energy intensity of the economy (E/GDP)	Carbon intensity of energy (F/E)	Total carbon emissions
1980-1990	-2.93%	-2.42%	-0.53%	-
1990-2000	-1.61%	-1.65%	0.04%	1.61%
2000-2007	-1.97%	-1.89%	-0.08%	0.31%

economic system, this slowdown of improvements implies that we may be reaching the practical limits of efficiency.

Globally, stabilisation of CO₂ to a safe level would require an 80–90 per cent reduction in current anthropogenic CO₂ emissions. Worldwide, they are actually growing by 3.4 per cent a year (average over 2000–2008 period).¹⁸⁷ At the same time, carbon intensity of energy is increasing by on average 0.33 per cent per annum. This trend is unlikely to change at least for the remaining 3-year term of the Kyoto protocol.

So is growth really possible?

Scenarios of growth and emission reductions

*If humanity wishes to preserve a planet similar to that on which civilisation developed and to which life on Earth is adapted... CO₂ will need to be reduced from its current 385 ppm to at most 350 ppm CO₂, but likely much less than that... If the present overshoot of this target CO₂ is not brief, there is a possibility of seeding irreversible catastrophic effects.*¹⁸⁸

James Hansen
NASA/Goddard Institute for Space Studies

Since changes to both carbon intensity of energy and the economy are assumed to play such a major role in mitigating strategies, we ask – *what declines in carbon intensity are necessary to meet a number of emissions scenarios ranging from the high risk, to what current science implies is necessary?*

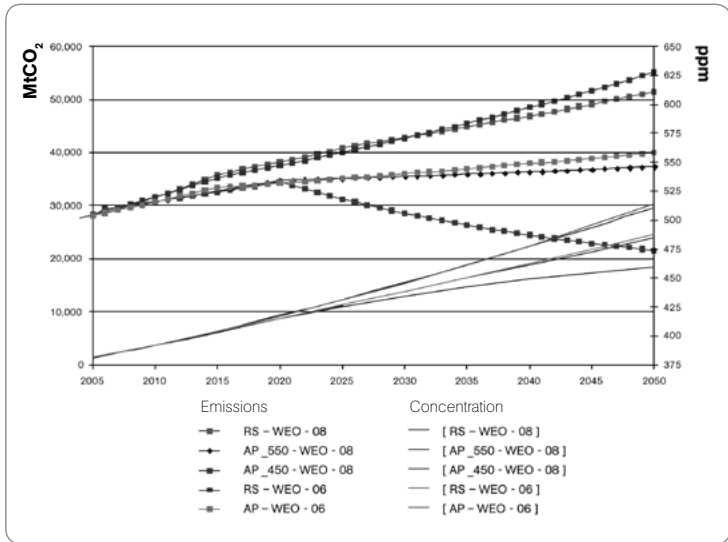
To address this question, we performed a number of analyses that examine the relationship between growth, carbon intensity of the economy, energy intensity of the economy (efficiency), carbon intensity of energy and emissions reductions. Focusing specifically on CO₂ rather than other greenhouse gas emissions, we modelled future consumption of fossil fuels. Since CO₂ produced by burning fossil fuels is approximately 70 per cent of all anthropogenically produced greenhouse gases, has a long atmospheric lifetime and is the best studied and modelled of the greenhouse gases, just focusing on CO₂ is a good starting point.

Unless otherwise stated, conversion and emissions factors and historical data on carbon emissions have been taken from the Carbon Dioxide Information and Analysis Centre, a section of the US Department of Energy.^{189,190} Data from the World Resources Institute Climate Analysis Indicators Tool were also used.¹⁹¹

The scenarios

Although the IPCC has produced a suite of scenarios that describe possible future emissions pathways, they are non-mitigating (i.e., they do not consider climate-

Figure 4. Comparison of the RS and AP scenarios presented in the *World Energy Outlook, 2006* to the updated *World Energy Outlook, 2008* RS and AP scenarios.



related policy), so will not include the impacts of current climate policies.¹⁹² They also incorporate a wide range of possible technical, social, and economic factors that are difficult to break down into their component parts.

Given this, more recent scenarios constructed by the IEA form the basis of our analysis, particularly as they do include mitigation policies. In this report, we explore the implications of the *World Energy Outlook – 2006* Reference (RS) and Alternative Policy (AP) scenarios. These scenarios are primarily driven by four parameters: economic growth, demographics, international fossil fuel prices and technological developments.

At the time of publication, the IEA had produced a further three World Energy Outlook reports since 2006, each containing a revision of these scenarios. However, on comparing the emission pathways for the 2007 and 2008 editions (shown in Figure 4) we find little divergence over the 50-year timeframe – the period that is the focus of our analysis.

The 2008 RS and AP-550 scenario are not dissimilar to the 2006 RS and AP scenarios. While there is a large difference between the AP-550 and AP-450, assumptions made

about the latter scenario are arguably questionable and unrealistic (see Box 15). Given that the RS and AP-550 scenarios are both similar to the *World Energy Outlook 2006* RS and AP scenarios, we base our analysis on the 2006 scenarios. In the 2009 edition (not shown), again there is minimal divergence from the RS. However, the only AP analysed is AP-450, which follows a similar trajectory to the *World Energy Outlook 2008* AP-450 scenario.

Box 15. WEO – 2008 Scenarios

Reference scenario

The reference scenario (RS) includes the effect of government policies up until mid-2008, but not new ones. For the RS, CO₂ is expected to have doubled by 2100, reaching 700 ppm (CO₂ only) and 1000 ppm (CO₂e). World primary energy demand increases at a slower rate than in previous RSs, *due to the recent economic slowdown and implementation of new climate policies*. This translates into annual carbon emissions that are just 1GtC less than the WEO 2007 RS. The RS also assumes decrease in CO₂ intensity by 1.7 per cent per annum (pa.)

Alternative scenarios

The alternative scenarios (APs) assume negotiations for the next phase of the Kyoto Protocol agree stabilisation targets of either 550 ppm CO₂e or 450 ppm CO₂e, which are achieved by 2200. These are both peak and decline scenarios. In other words, the target atmospheric concentration of CO₂e is overshoot, and subsequently reduced. Given this, in the AP-450 scenario, atmospheric concentrations of CO₂ peak between 2075 and 2085, and then begin a long-term decline to 2200. For the AP-550 scenario, atmospheric concentrations of CO₂ peak in the middle of the next century and slowly decline to 550 ppm CO₂e by 2200. Scenarios are met through three key climate policy mechanisms – cap-and-trade, sectoral agreements, and national policies and measures.

In order to meet these targets, the scenarios assume significant growth in low-carbon energy such as: hydroelectric power, nuclear, biomass, other renewables and carbon capture and storage.

AP-550-AS

AP-550 assumes that while world primary energy demand increases by 32 per cent over the period 2006–2030 (0.4 per cent slowdown in growth rate compared to the RS), emissions would rise by no more than 32,900 MtCO₂ in 2030 and decline thereafter. This requires a \$4.1 trillion investment into low carbon energy related infrastructure or 0.2 per cent of annual GDP.

The change in energy mix results in a decline in CO₂ intensity by 2.6 per cent pa. This is due to both the increase in low carbon energy and the decrease in the average quantity of CO₂ emitted per tonne of fossil fuel energy. By 2030, low carbon energy would account for 26 per cent of the primary energy mix compared to 19 per cent in 2006. This level of decarbonisation of the power sector is equivalent to seven coal-fired plants and three gas-fired plants with carbon capture and storage (CCS), 11 nuclear plants, 12,000 wind turbines each year and the equivalent of three, Three Gorges Dams every two years. In addition, emissions from fossil fuel energy fall from 2.94 tonnes/toe in 2006 to 2.83 tonnes/toe in 2030. This is due to a falling share of coal in the primary energy mix.

AP-450-AS

AP-450 requires that CO₂e emissions fall dramatically in 2020 from 35,000 MtCO₂e to 27,500 MtCO₂e by 2030 and 14,000 MtCO₂e by 2050. Energy efficient improvements at both production and end-use levels result in a low growth rate in energy demand (0.8 per cent pa). By 2030, low carbon energy will account for 36 per cent of the global primary energy mix (including CCS), costing \$9.3 trillion or 0.6 per cent of annual world GDP. Fossil fuels still account for 67 per cent of the primary energy demand in 2030; however, there is an assumption that CCS technologies will be more widespread in the power generation sector and will also be introduced into industry. Additionally, it is assumed 13 nuclear power stations need to be built each year and biofuels are more widespread the transport sector. Beyond 2030, the power sector becomes 'virtually decarbonised' with a strong emphasis on CCS in the power and industrial sectors and electric, hybrid and biofuels in the transport sectors (private and goods vehicles, shipping and aviation).

Between 2006 and 2030, there is:

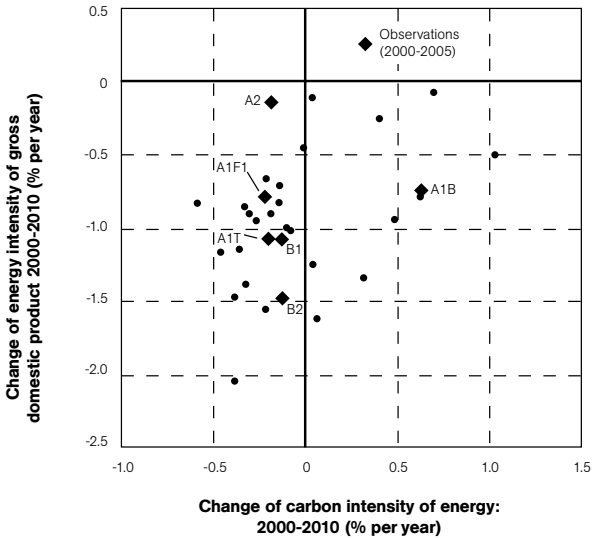
- a tenfold increase in wind, solar and other renewables;
- an increase in modern biomass (modern bioenergy plants that use organic waste or cultivated feedstocks) by almost 80 per cent;
- a near doubling of nuclear energy.

There are three fundamental critiques of these scenarios, however. First, it is noteworthy that recent research by Lowe *et al.* has stated that in order to have less than a 50 per cent change of **not** exceeding 2°C, emissions need to peak by 2015 and fall by 3 per cent each year thereafter. Neither the RS nor the AP scenarios achieve such an early and dramatic peak and decline scenario. Lowe *et al.* also note that even if emissions peak in 2015, there is still a one-in-three chance that near-surface temperatures will rise by more than 2°C in 100 years' time.¹⁹³ The IEA, however, dismisses a scenario that does not achieve overshoot stating: 'A 450 stabilisation trajectory without overshoot would need to achieve substantially lower emissions in the period up to 2020 and, realistically, this could be done only by scraping very substantial amounts of existing capital across all energy-related industries. In any case, given the scale of new investment required, **it is unlikely that the necessary new equipment and infrastructure could be built and deployed quickly enough to meet demand.**'¹⁹⁴ Wigley *et al.* also note that a policy that allows emissions to follow an overshoot pathway means that in order to recover to lower temperatures within a century timescale, we may, for a period, require negative global emissions of CO₂.¹⁹⁵

Second, the assumptions about growth in capacity of CCS are also overly optimistic. The consensus view is that CCS may be commercially viable by 2020; however, a number of analysts believe even this is an optimistic scenario suggesting that 2030 may be more realistic.

Third, given the optimism attached to CCS as a viable technology in the near future, the assumption that CO₂ intensity can feasibly decline by 2.6 per cent per year can also be viewed as over optimistic. Figure 5 produced by Pielke *et al.* compares predicted (IPCC scenarios) and observed changes in energy intensity the economy carbon intensity of energy. Observations (2000–2005) imply both an increase in energy intensity of the economy and carbon intensity of energy by approximately 0.25 and 0.3 per cent pa respectively.

Figure 5. Assumed decarbonisation in the 35 IPCC scenarios for 2000–2010 compared to observations between 2000 and 2005.¹⁹⁶



World Energy Outlook 2006 Scenarios

As already discussed, *The World Energy Outlook 2006* provides two scenarios: RS and AP.¹⁹⁷ The RS (business-as-usual case) provides a baseline projection of energy usage, or carbon emissions, in the absence of further policy changes from mid-2006. As such, by 2030, the RS projects global primary energy demand increases of 53 per cent, with over 70 per cent of this coming from developing nations, led by China and India.

Conversely, the AP scenario estimates the impact of implementing all currently proposed policy changes on energy use/carbon emissions, such as speeding up efficiency improvements or shifting to renewable energy sources. By 2030, global energy demand is reduced by 10 per cent, mainly due to the improved efficiency of energy use. Twenty-nine per cent of the decrease in emissions is expected to be achieved by electricity end-use efficiency and 36 per cent by fossil fuel end-use efficiency.

These scenarios are both based on average GDP growth of 3.4 per cent between 2004 and 2030 as well as average population growth of 1 per cent. We assume that beyond 2030 to 2050, GDP would grow at the rate of 2.9 per cent a year, the 2030 growth rate.

In analysing the data, we separate two important components of the carbon intensity of an economy: efficiency in usage of energy (energy intensity of the economy – see Equation 1) and the carbon intensity of energy. The interaction of these elements is described in Equation 3.¹⁹⁸

Equation 3

$$\frac{F}{G} = \frac{F}{E} \times \frac{E}{G}$$

$$\frac{\text{tonnes CO}_2}{\text{thousand USD}} = \frac{\text{tonnes CO}_2}{\text{toe}} \times \frac{\text{toe}}{\text{thousand USD}}$$

Where F is global CO₂ emissions from human activity (in tCO₂), E is total primary energy supply (in tonnes of oil equivalent) and G is world GDP (in ‘000s \$US).

Using the two WEO scenarios of total consumption of energy, including electricity supply, we calculated energy intensity of the economy and carbon intensity of energy.

It is noteworthy that the emissions calculations made here only used primary energy supply projections (coal, oil, and natural gas). Other forms of energy usage, such as biomass, nuclear and hydroelectric power were assumed to have no carbon emissions.¹⁹⁹ This assumption was made for ease of calculation, as sufficiently detailed projections for the type of biomass in use were not available to allow emissions projections. Additionally, land-use changes from hydroelectric power projects were not included. Given this, we expect all our calculations to be conservative.

In extending the scenario to 2050, we have projected the energy supply growth for each fuel type using the annual growth rates estimated for 2015–2030, employing the same method to project total final consumption (TFC).

In describing the RS, the IEA states that the energy intensity of the economy will decline by 1.4 per cent on average until 2030.²⁰⁰ Again we have used this figure to project forward until 2050. No specific growth rate is suggested for the AP scenario,

but it does imply a faster rate of improvements in energy intensity of the economy. Based on historical precedents we assume an ambitious 2.0 per cent decline in energy intensity between 2004 and 2015, 2.2 per cent between 2015 and 2030 and 2.6 per cent between 2030 and 2050.

Model assumptions

We used a globally aggregated Earth system model – the Integrated Science Model (ISAM) global carbon model to predict the effect of emissions on atmospheric concentrations of CO₂. The ISAM model is available online and has been used widely in the IPCC assessment reports and climate policy analyses related to greenhouse gas emissions.²⁰¹ The carbon-cycle component is representative of current carbon-cycle models.²⁰² Model iterations were run with the IPCC B scenario for carbon emissions from land-use changes.²⁰³ Emissions of other greenhouse gases besides CO₂ were also assumed to follow the IPCC B scenario.

Even though the model provides a projection of median temperature increases, these have not been reported due to the uncertainty in projecting temperature changes with increasing greenhouse gas concentrations.²⁰⁴ We have, therefore, confined ourselves to demonstrating the necessary improvements in carbon intensity to meet various CO₂ emissions targets.

To test whether the projections correspond to a sustainable economy, we examine the potential for overshooting of CO₂ emission targets, with a given level of energy intensity of the economy improvements, energy demand and GDP growth. We have used the SIMCAP modelling platform developed by Malte Meinshausen to generate potential target emissions pathways.²⁰⁵ The model uses an Equal Quantile Walk (EQW) method to create more plausible scenarios for emissions paths out of the infinite combinations of yearly emissions that might achieve the targets.²⁰⁶

We have reported the results for target peaks of atmospheric CO₂ concentrations of 350 ppm, 400 ppm, 450 ppm, 500 ppm and 550 ppm CO₂. Note that we have confined our analysis in this section to actual CO₂ emissions, ignoring the effect of other greenhouse gases. This was necessary because of the limits of the model in converting other emissions into CO₂e emissions. Thus, the actual warming effect is greater than that created by the CO₂ emissions. Based on current proportions, CO₂e (Kyoto gases only) would be around 50 ppm greater; for example, 385 ppm CO₂ is around 435 ppm CO₂e.

The EQW method was used to create the emission scenarios required to meet the target, with emissions reductions starting in 2007 for the OECD and 2010 for other regions of the world. Using this scenario and the previously defined rates of GDP growth, we have calculated what the necessary energy intensity and/or carbon intensity improvements would have to be to remain below the CO₂ targets. The EQW method was also used to create the post-2050 emissions pathways that would be necessary under the RS and AP scenarios to meet the targets.

Recent evidence and modelling has brought further clarity to the debate over feedback considerations. In the carbon-cycle, faster rates of emissions growth and accumulation of CO₂ in the atmosphere will weaken the rate at which it can be absorbed into the oceans or terrestrial carbon sinks (see Box 11). While we have excluded such feedbacks from the main analysis, we have provided estimates using these data separately.

Peak Oil

Although increasingly warning of production capacity constraints, the IEA makes no detailed mention of the possible physical limits to continuing exploitation of fossil fuels to drive the global economy. That is, with the single exception in one media interview, when Fatih Birol, the IEA's chief economist, said, 'In terms of the global picture, assuming that OPEC will invest in a timely manner, global conventional oil can still continue, but we still expect that it will come around 2020 to a plateau.'²⁰⁷ In other words, a peak and long-term decline in the global production of oil. Evidence is presented later in this report on the likely onset of Peak Oil.

Projections for oil and gas production were obtained from Colin Campbell and the Association for the Study of Peak Oil (ASPO).²⁰⁸ Given the constraints in building and developing alternative sources of energy, such as nuclear or hydroelectric power stations, we have assumed that the energy requirements left unfilled because of the shortage of oil and gas will be filled by replacing those fuels with coal – a phenomenon that appears to be occurring already.²⁰⁹ This has significant effects on the carbon intensity of energy. While the rate of supply side efficiency improvements to the energy intensity of the economy are also dependent on the fuel mix, this substitution serves as a first order estimate of the effects of Peak Oil on anthropogenic greenhouse gas emissions.

As CCS is still an immature technology, yet to be proven at scale, we do not assume that it plays a role in reducing the carbon intensity of the economy.²¹⁰ The future role of CCS is discussed in more detail later in this report.

We have also erred on the side of caution by not factoring in the declining net energy gains from fossil fuel extraction as more marginal stocks of oil, gas and coal are exploited. Increasing amounts of energy must be used to exploit heavy oils and tar sands which would have deleterious effects on the energy intensity of the economy.²¹¹ But without a very comprehensive and detailed global energy model, predicting such effects would be difficult. Additionally, using coal that is higher in moisture or otherwise less efficient for electricity production would have similar negative effects on the energy intensity of the economy. We have not modelled this here for lack of data.

Results

As shown in Figure 6, the scenarios developed by the IEA would lead to extremely high concentrations of atmospheric CO₂, with the RS breaching the upper limit of our most generous target range in 2047. Even the optimistic AP scenario, would lead to atmospheric concentrations of CO₂ of 487 ppm by 2050.

A possible emissions scenario that would seek to stabilise atmospheric CO₂ concentration at 500 ppm after 2050 is shown in Figure 7. Given the pre-2050 emissions pathway of the alternative policy scenario, it is impossible to prevent an overshoot of the target. The changes in emissions levels needed to even bring about stabilisation after an overshoot are quite dramatic. As Figure 7 shows, if the alternative policy scenario is

Figure 6. IEA scenario emissions and resulting atmospheric CO₂ concentrations.

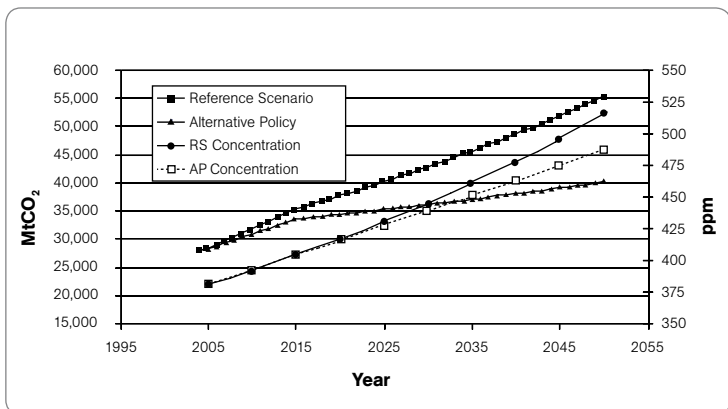


Figure 7. Possible post-2050 emissions scenarios.

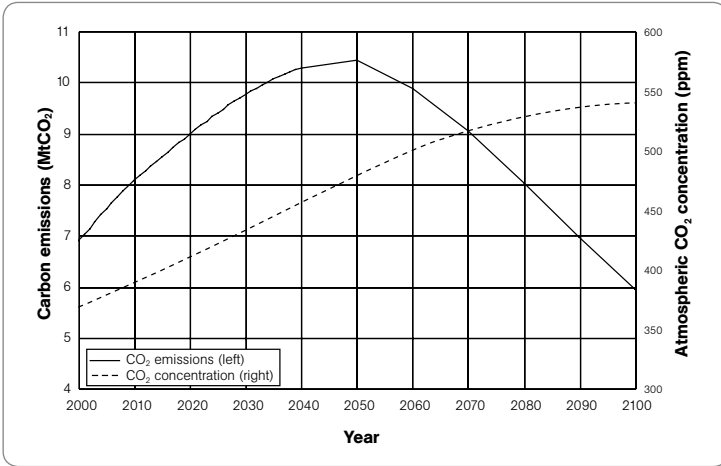
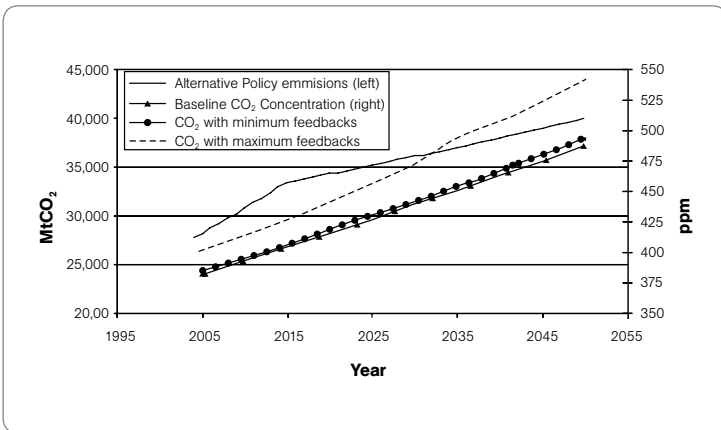
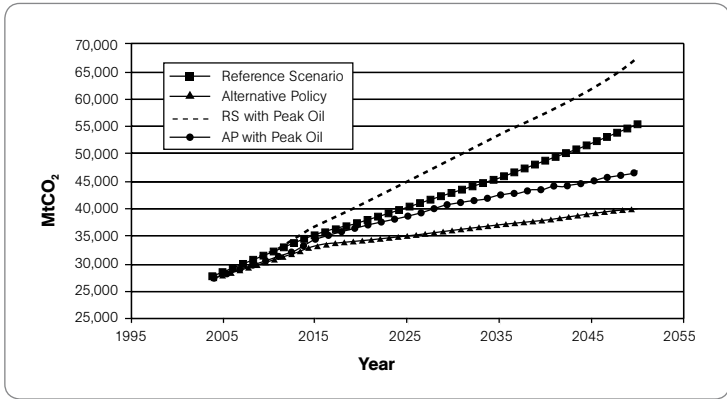


Figure 8. The impact of carbon cycle feedbacks on atmospheric concentration of CO₂.



followed until 2050, immediately thereafter carbon emissions would still have to be curtailed by roughly 1.1 per cent annually to even stabilise atmospheric CO₂ below 550 ppm. This does not account for the impact of carbon-cycle feedbacks, however.

Figure 9. Effect of declining oil production on emissions.



If we take into account the effects of carbon-cycle feedback mechanisms, the atmospheric concentrations of CO₂ corresponding to a given level of emissions increases over time. As climate models disagree about the magnitude of the feedback effect, we have demonstrated the range of possible CO₂ concentrations in Figure 8. Data on the potential carbon-cycle feedbacks were taken from the C⁴MIP Model Intercomparison.²¹² In the worst-case scenario, the atmospheric concentration of CO₂ is about 10 per cent larger than previously modelled.

The situation becomes much worse when the Peak Oil projections are combined with the possible efficiency improvements described in the IEA scenarios (see Figure 9). In the AP scenario, resulting emissions from the projected change in the fuel mix would be nearly 17 per cent higher than the IEA projections. This would bring projected atmospheric CO₂ concentration to 501 ppm in 2050 (note, concentrations are not shown on the graph). Peak Oil, therefore implies that proceeding with every proposed improvement to energy intensity and adoption of cleaner fuels will not be sufficient to prevent a breach of even the most generous target and thus potentially disastrous climate change.

Emissions scenarios with target CO₂ concentrations

The second phase of our analysis compared possible emissions scenarios with target pathways that would generate specified levels of atmospheric CO₂ concentrations. Using the EQW method, emissions scenarios were created to match the targets of 350 ppm, 400 ppm, 450 ppm, 500 ppm and 550 ppm. Figure 10 shows the emissions pathways as compared to the IEA pathways.

Figure 10. Possible emissions scenarios to meet various atmospheric CO₂ concentration targets.

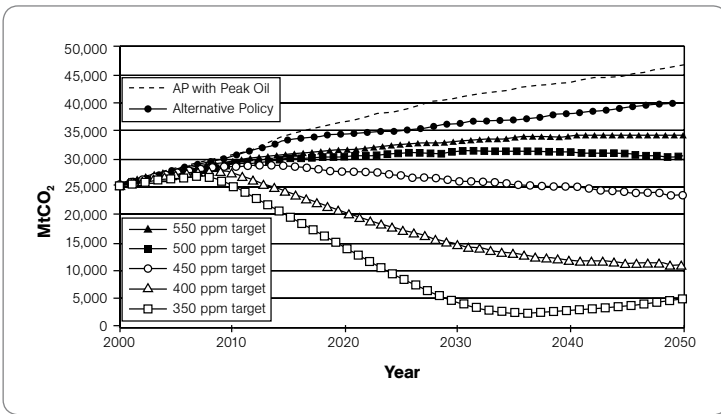
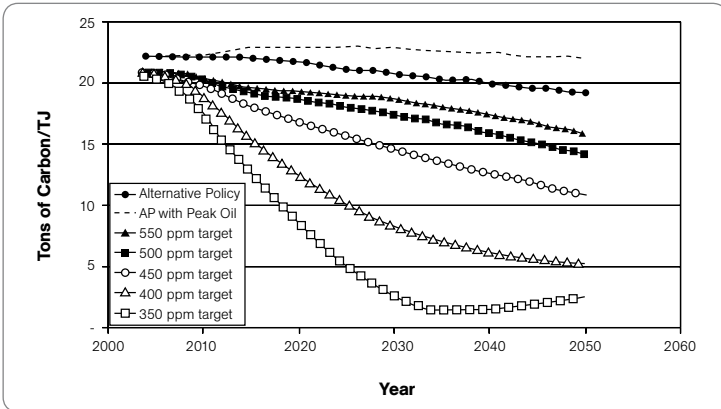
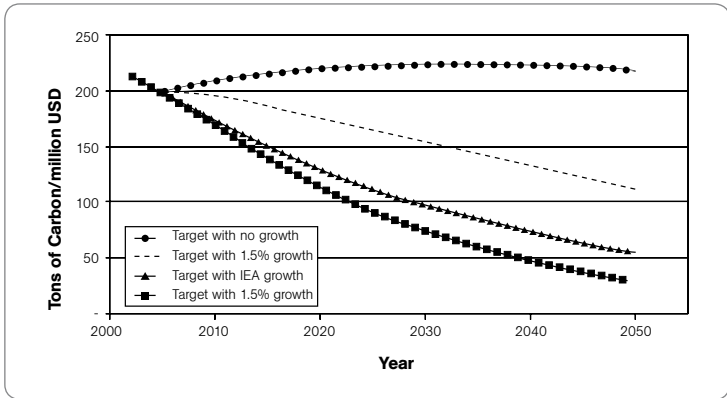


Figure 11. The growing gap in the carbon intensity of energy.



We then examined the gap that would have to be plugged by changes in carbon intensity of energy to meet the targets. Maintaining the assumptions in the alternative policy scenario about the improvements to the energy intensity of the global economy and using the stylised emissions pathway that would meet the target atmospheric concentrations of CO₂, we can find a typical pathway of improvement in the fuel mix that would enable growth at the rate specified in the IEA scenarios. As shown in Figure 11, the aggressive advancement of renewable energy in the AP scenario does not meet the needs of an emissions pathway that could mitigate climate change.

Figure 12. Improvements needed to meet the target emissions pathway at different levels of growth.



The projection for a decline in oil production and substitution by dirtier coal energy sources counterbalances the other improvements in the fuel mix. Despite the scenario assuming about 25 per cent greater use of nuclear power and non-hydroelectric renewable energy sources than in the RS, which already includes almost 10 per cent per annum average increases in renewables, the effects of declining oil production mean that the carbon intensity of energy remains about the same over time. This demonstrates that without radical changes in lifestyle in terms of energy usage or even faster moves towards non-fossil-fuel energy sources, it will not be possible to have economic growth at the rate indicated.

Looking at the overall carbon intensity of the economy, meaning that we allow variable improvements in both the carbon intensity of energy and energy intensity of the economy, Figure 12 shows that kind of improvement that would be needed to meet the target emissions pathway at different levels of growth.

Even at 1.5 per cent growth, the global economy would need to reduce its carbon intensity by 71 per cent between 2006 and 2050, equivalent to a 1.3 per cent average annual decline. But, this assumes a steady improvement, since following a different trajectory – for example, with delayed measures to improve the carbon intensity – would cause cumulative emissions to increase, and an overshoot of the target.

Any delay in improvements would have to be paid for with even greater improvements in the future to ensure that atmospheric carbon concentrations do not peak above

Box 16. Historical precedents for rapid changes in carbon intensity

An absolute annual reduction in CO₂ emissions greater than 3 per cent is rarely considered to be a viable option.²¹³ Worse still, where mitigation policies are more developed, emissions from international aviation and shipping are not included. For example, Anderson *et al.* note that the UK's CO₂ emissions are, on average, 10 per cent greater than official records for this reason.²¹⁴

In the Stern Review, historical precedents of reductions in carbon emissions were examined. Their analysis found that annual reductions of greater than 1 per cent have 'been associated only with economic recession or upheaval'.²¹⁵ Stern points to the collapse of the former Soviet Union's economy, which brought about annual emission reductions of over 5 per cent for a decade. While France's 40-fold increase in nuclear capacity in just 25 years and the UK's 'dash for gas' in the 1990s both corresponded, respectively, with annual CO₂ and greenhouse gas emission reductions of only 1 per cent.

In 1990, the Dutch government proposed to increase the rate of energy efficiency from 1 per cent per year to 2 per cent per year. The pledge was considered a 'real test of strength', by the Ministry of Economic Affairs. This was against the backdrop for what was actually achieved generally during the last century of 1.2 per cent per year. However, the target up to 2010 was later revised to 1.3–1.4 per cent per year.²¹⁶

the maximum of the target range, namely 500 ppm CO₂. The question remains as to whether such improvements could be made.

Would the global economy manage to lower its carbon intensity by 2.7 per cent per year on average (the necessary improvement to meet the 500 ppm target with 3 per cent growth levels) while maintaining growth? Historical indicators are not positive, with the average annual declines of carbon intensity between 1965 and 2002 being just 1.2 per cent. Worse still, between 2000 and 2007, improvements in energy intensity of the economy slowed to an average of just 0.4% each year. Over the same period, carbon intensity of the economy increased by on average 0.37% per year.

Figure 13 again highlights the gaps between the AP scenario and the targets, much as Figure 12. The scenarios are clearly way above even the riskiest target level.

Figure 13. The gap between scenarios and targets.

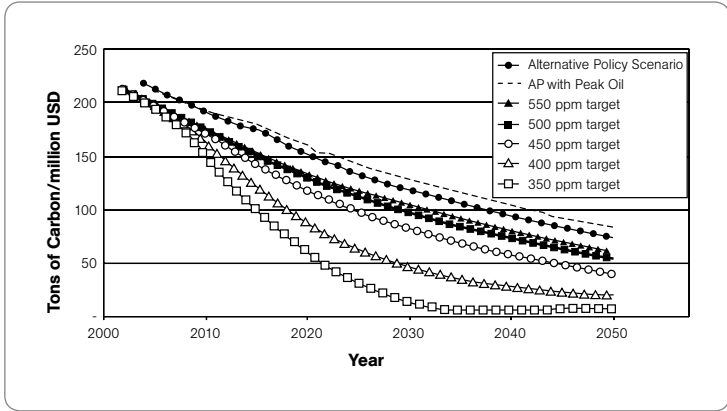
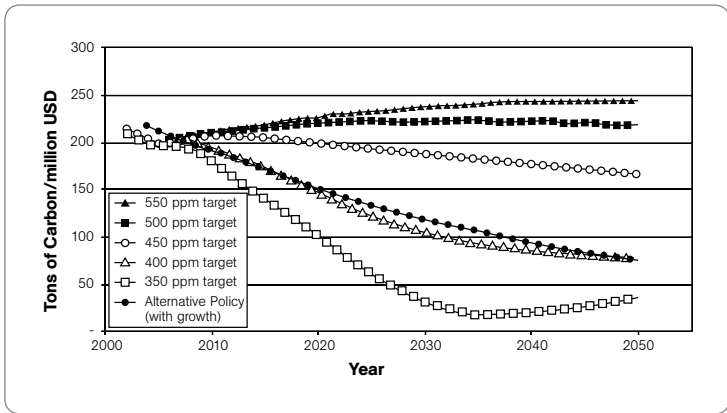


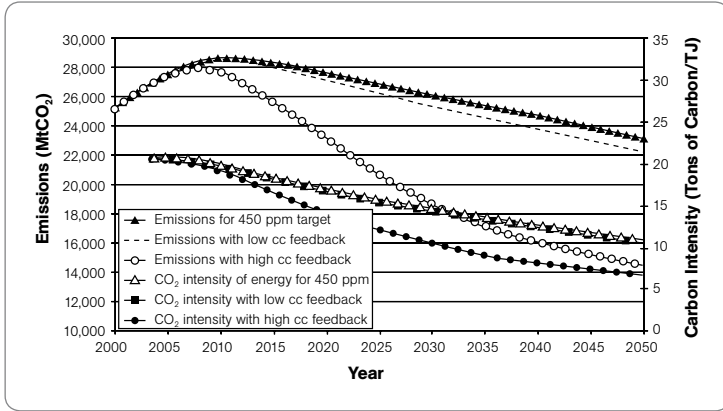
Figure 14. Target carbon intensities with no economic growth.



Even if growth were to cease, implying a decline in global per capita incomes because of population growth, we could not be complacent on the technology and energy front, as shown in Figure 14. Maintaining a low risk profile and keeping ambient CO₂ concentrations below 400 ppm would require similar levels of investment in energy efficiency and emissions reductions as described in the AP scenario, all without any increase in overall economic activity.

As a final analysis, we looked at the effect of carbon-cycle feedbacks on the need for carbon intensity improvements and emissions reductions. To meet the same 450 ppm

Figure 15. Potential effects of carbon cycle feedbacks.



target for atmospheric CO₂ concentrations in a coupled carbon-cycle model, the actual emissions pathway must correspond to a concentration of between 410 ppm and 445 ppm in an uncoupled carbon-cycle model. The results are shown in Figure 15, and demonstrate that the effect of carbon-cycle feedbacks can be significant.

The following sections explore some of the factors that may modify these scenarios. They seek to indicate the relative likelihoods of the range of different possible outcomes – better or worse – are more probable.

Since our main work was completed, Professor Kevin Anderson of the Tyndall Centre for Climate Change Research at Manchester University also looked at a range of scenarios for growth, greenhouse gas concentration levels and global warming.²¹⁷

Assuming that growth continued, he looked at the rate of emissions reductions that would be needed to achieve greenhouse gas concentration levels commensurate with a 2, 3 or 4°C temperature rise. Most, of course, agree that temperature rise above two degrees represents unacceptable, dangerous warming. Anderson's conclusion was stark: 'Economic growth in the OECD cannot be reconciled with a 2, 3 or even 4°C characterisation of dangerous climate change.'²¹⁸

Peak Oil, Gas and Coal

If we could spend the oil age in an Irish pub... the glass was more or less full in 1900, just about half full in 2000 and there are a few little dregs left at the end of this century.

Dr Colin Campbell (1 February, 2007)

*My father rode a camel. I drive a car. My son flies a jet plane. His son will ride a camel.*²¹⁹

Saudi saying

Supplying the world with all the crude oil and natural gas it wants is about to become much harder, if not impossible. For oil, the horizon of the global peak and decline of production appears close and that for gas not much further behind. When demand exceeds production rates, the rivalry for what remains is likely to result in dramatic economic and geopolitical events that could make the financial chaos of 2008 in Europe and the USA seem light-hearted. Ultimately, it may become impossible for even a single major nation to sustain an industrial model as we have known it during the twentieth century.²²⁰

Counter-intuitively, the imminent global onset globally of the peak, plateau and decline of the key fossil fuels, oil and gas, will not help arrest climate change. If anything, it could be a catalyst for worse emissions and accelerating warming. For example, in October 2009, the UK Energy Research Centre (UKERC) reviewed the current state of knowledge on oil depletion.²²¹ The study argued as we advance through peak oil:

... there will be strong incentives to exploit high carbon non-conventional fuels. Converting one third of the world's proved coal reserves into liquid fuels would result in emissions of more than 800 million tonnes of CO₂, with less than half of these emissions being potentially avoidable through carbon capture and storage.

In other words, with the analyses by Meinshausen and Allen discussed earlier in this report in mind, without extensive investment in low carbon alternatives to conventional oil, and policies that encourage demand reduction, Peak Oil is likely to drive emissions further towards a threshold of dangerous climate change.

Box 17. Peak Oil and food production

Increased fossil energy prices will in turn cause the price of food to increase significantly. On average, 2.2 kilocalories of fossil fuel energy are needed to extract 1 kilocalorie of plant-based food.²²² In the case of meat, the average amount of kcal fossil energy used per kcal of meat is much greater, with an input/output ratio of 25.²²³

In early 2008, the UN World Food Programme had to reassess its agreed budget for the year after identifying a \$500 million shortfall. It found that the \$2.1 billion originally allocated to food aid for 73 million people in 78 countries would prove to be inadequate because of the rising costs of food. Higher oil and gas prices have contributed to this by increasing the costs of using farm vehicles and machinery, transporting food and manufacturing fossil-fuel-dependent input such as fertiliser. The move to grow biofuel crops has also exerted upward pressure on food prices by leaving less productive land available to grow crops.

The global economy is still heavily dependent on fossil fuels. Oil remains the world's most important fuel largely because of its role in transport and agriculture and the ease with which it can be moved around.

The historical pattern has been for industrial societies to move from low-quality fuels (coal contains around 14–32.5MJ per kg) to higher quality fuels (41.9 MJ/kg for oil and 53.6 MJ per kg), and from a solid fuel easily transported and therefore well suited to a system of global trade in energy resources.²²⁴

Now, almost all aspects of our economy are dependent on a constant and growing supply of cheap oil, from transport to farming, to manufacturing and trade. In the majority world, where too many people live close to, or below the breadline, the long tail of green revolution agriculture depends on pesticides and fertilisers that need large amounts of fossil fuels. The implication of any interruption to that supply, either in terms of price or simple availability, means a significant shock to the global economy. Everyone will be affected, but some more than others.

Box 18. We've been here before

The world oil crises in the 1970s provide some idea of how the effects of Peak Oil may ricochet through the economy. The two world oil crises in the 1970s (the most significant occasions when demand exceeded supply due to politically caused interruptions) caused widespread panic that the economy would fall into a global depression. During the first oil embargo in 1973, oil supplies only fell by 9 per cent. The second oil crisis caused by the Iranian oil cut-off resulted in a fall in oil production by 4 per cent.²²⁵ Both world oil crises were followed by recession, resulting in economic hardship, unemployment and social unrest around the world.²²⁶

Interestingly, the first and second oil crises are the only recorded times in the industrial epoch where energy efficiency improvements have actually resulted in a decrease in demand for energy. This shows how a strong price signal, aggressive government policy and awareness can work together to decrease energy demand.

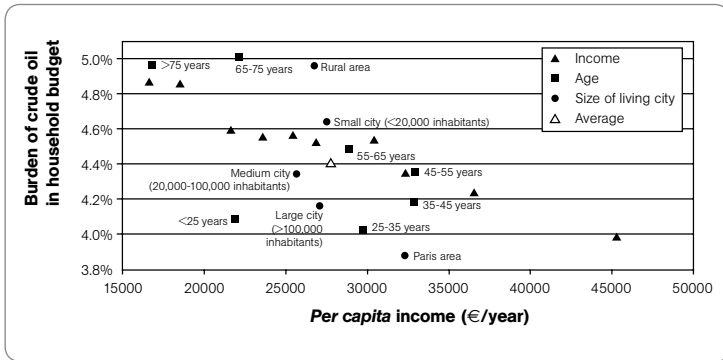
The price burden of crude oil

Recent research explored the price burden of crude oil on French households in 2006.²²⁷ This is the first analysis of this type. Other analyses have only focused on direct domestic energy consumption (electricity and gas).^{228,229,230} This study, however, explores the contribution of indirect or 'embodied' energy within goods and services. The results and can be taken to be broadly consistent with other developed nations.

The analysis found that in 2006, the average burden of crude oil was equivalent to 4.4 per cent of the total budget of a typical French household. This figure, however, varied significantly depending on income, age or the size of their city of residence. The results are presented in Figure 16. This provides some indication of the vulnerability to oil price rises. In general, Figure 16 shows the largest burden is likely to be experienced by the elderly and low-income groups. This illustrates that changes in oil prices are an acute social justice issue.

In an international context, different government responses to oil price rises can also radically alter the consequences for developing countries. Following the 1973 oil price shock, relaxed monetary policy in rich countries caused low to negative real interest rates on hard currencies. As well as maintaining demand for poor countries' exports

Figure 16. Dependence of the contribution of crude oil to household's budget as a function of per capita income, age of the household's reference person, and the type of residential area.²³¹



this also laid the foundations for the Latin American debt crisis. But following the 1979 oil price shock, rich countries' fear of inflation created a triple blow for their poorer relations. Economist David Woodward describes the consequences of tightening monetary policy, 'demand contracted, developing countries' export prices collapsed and real interest rates increased dramatically to historically high levels'.²³² Consequently, the price of oil imports doubled 'overnight' and interest rates on commercial foreign debts doubled over the next three years.

Even at oil prices prevailing in early 2004, the IEA believed that oil-importing developing countries were being seriously disadvantaged.²³³ As the International Monetary Fund (IMF) observes, although the so-called Heavily Indebted Poor Countries (HIPCs) 'account for only a small share of global GDP, many of them are among the most seriously affected by higher oil prices'.²³⁴

The IMF points out that 30 of the 40 HIPCs are net oil importers, making them particularly sensitive to price fluctuations. Their problems are compounded by several interconnected economic factors including: low per capita incomes, high level of oil imports relative to GDP, large current account deficits, high external debt, and limited access to global capital markets. Altogether, according to the IMF, this means that, 'the impact of higher oil prices on output is relatively large, as it will have to be met primarily through a reduction in domestic demand'.²³⁵ This is economists' speak for the poor getting poorer.

Timing of Peak Oil

*We may argue about when the peak is, but it doesn't change the argument that it is coming.*²³⁶

Robert Kaufmann, Energy Economist at Boston University

The actual global peak year will only be known when it has passed, but most estimates suggest that we are either at, or very close to this point. At most it is one or, less likely, two decades away. Against a background of rising demand, 'peaking' will result in a major shock to the global economy. But, even before then, an opening gap between production and demand is already driving prices up.

The recent review published by UKERC warned that, almost unequivocally, peak production will occur before 2030, with a significant risk that this will occur before 2020.²³⁷ Estimates of the precise onset of Peak Oil range from 2006 to 2030 (Table 6). The higher-end estimates are by and large due to exaggeration of technical reserves. A constant flow of new studies and industry leaks, however, point towards a downward revision of potential reserves.

Actual technical reserves of oil are often very different from published reserves, the former rarely changing and the latter being related to political circumstance (often overestimated because of poor data, to bolster financial investment, political and institutional self interest, and other complicating factors). But, despite the variety of different estimates, many credible analysts have recently become much more pessimistic about the possibility of finding the huge new reserves needed to meet growing world demand, and even the most optimistic forecasts suggest that world oil peaking will occur in less than 25 years.

A central problem in the estimation of 'real' oil reserves is that not all oil companies work to the same standards of reporting. Whilst the US Securities and Exchange Commission sets rules for how to report reservoir estimates, only US and major international companies generally abide by those standards, reporting is not always performed reliably.^{238,239} Jeremy Leggett, an expert on Peak Oil, reports in his book *Half Gone* that reporting by Organisation of Petroleum Exporting Countries (OPEC) is usually particularly dubious: 'Middle East official reserves jumped 43 per cent in just three years [during the 1980s] despite no new major finds.'²⁴⁰ Additionally, Saudia Arabia has posted a constant level of reserves (260 billion barrels) over the past 15 years, despite the fact that it has produced over 100 billion barrels in the same period.²⁴¹

Table 6. Projected dates of reaching 'Peak Oil'.²⁴²

Projected Date	Source of Projection	Background/Reference
2006–2007	Bakhitari	Iranian Oil Executive
2007–2009	Simmons	Investment Banker
After 2007	Skrebowski	Petroleum Journal Editor
Before 2009	Deffeyes	Oil company geologist (ret.)
Before 2010	Goodstein	Vice Provost, Cal Tech
Around 2010	Campbell	Oil company geologist (ret.)
After 2010	World Energy Council	NGO
2010–2020	Laherrere	Oil company geologist (ret.)
2016	EIA (Nominal)	US Department of Energy
Before 2020	UKERC	UK energy research body
After 2020	CERA	Energy consultants
2025 or later	Shell	Major oil company
No visible Peak	Lynch	Energy economist

The North Sea is the only place where a significant new discovery has been made outside of OPEC nations, Russia and Alaska in the past four decades. Both Norway and the UK are seeing decreases in the production from the region to the extent that the UK no longer exports oil. Furthermore, no new giant oilfields are replacing those which have already passed their peaks.

Of all the oil resources remaining:²⁴³

- 62 per cent is in the Persian Gulf;
- 10 per cent is in Africa, mostly Angola, Libya, and Nigeria;
- 10 per cent is in the former Soviet Union (FSU), mostly Russia, Kazakhstan, and Azerbaijan; and
- 10 per cent in Latin America, mostly Venezuela.

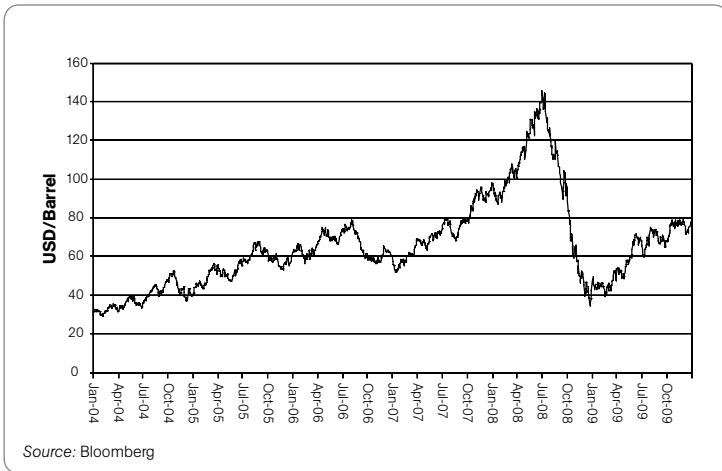
A failure to grasp the problems associated with Peak Oil was, until recently, a serious blind spot in many official government policies and reviews. For example, ASPO commented on the 2006 Stern Review: 'It fails to take note that oil and gas, which drive the modern economy, are close to peak, and will decline over most of this century to near exhaustion. The coal resources are indeed large, but the coal-burning airliner has yet to take off.'²⁴⁴

Whilst there is considerable uncertainty surrounding future oil reserves, and the field is surrounded by intense debate, the current view appears to be converging towards the view that Peak Oil is a very real and impending problem that could have catastrophic implications for the global economy, to the extent that it is gradually filtering into the A-list of political concerns with then Secretary of State for Environment, Food and Rural Affairs, David Miliband addressing an audience at the University of Cambridge in March 2007 stating: 'The time is right to look at what it would mean for the UK over the period of 15 to 20 years to create a post-oil economy – a declaration less of 'oil independence' and more the end of oil dependence.'²⁴⁵

More recently, the IEA has begun to identify the problems of Peak Oil. The *Medium Term Oil Market Report* published by the IEA (an official advisor to most of the major economic powers) reported in 2008 that: 'there will be a narrowing of spare capacity to minimal levels by 2013'. Since the previous year alone it had made, 'significant downward revisions' on 'both non-OPEC supplies and OPEC capacity forecasts'.²⁴⁶ The fuel price volatility of the last two years looks to be a foretaste of a far more massive crunch that will follow as the graph lines for global oil demand and supply head in opposite directions.²⁴⁷ The IEA's motto – 'energy security, growth and sustainability' – appears to be the antithesis of the situation that it surveys.

Since UK North Sea production peaked around 1999, hopeful eyes have been focused on the major producers like Saudi Arabia to keep the economy's arteries full of oil.²⁴⁸ But, looking ahead, Saudi Arabia appears to have other ideas. Over the next 12 years it intends to spend around \$600 billion (about the same staggering figure that the USA earmarked for propping up its financial system) on a massive domestic infrastructure programme, including power stations, industrial cities, aluminium smelters and chemical plants. And, while doubts persist that its reserves are a lot less than publicly stated, guess what: all these new developments will be powered with Saudi oil. The rest of the world should not hold its breath waiting to be rescued.²⁴⁹

Figure 17. The rise in the price of Light Crude (NYMEX) between January 2004 and December 2009 (current \$US per barrel).



Already the cost of a barrel of oil has risen almost 14-fold in the last decade reaching \$147 a barrel in July 2008 (Figure 17). While the price dropped in late 2008 to \$40 a barrel, they have doubled again since. Oil prices are becoming increasingly volatile due to declining indigenous production and growing reliance on international markets. It is noteworthy that that several analysts forecast oil prices could rise to \$200 to \$300 a barrel in the near future.^{250,251}

The energy return on investment

*The first half of the total oil resource is easy to extract, the second half is hard. We will transition from oil fields that are shallow, big, onshore, safe, and close, to fields that are deep, dispersed, offshore, remote, and unsafe.*²⁵²

Professor Michael Klare, author of *Blood and Oil* (2004)

*[It] takes vast quantities of scarce and valuable potable water and natural gas to turn unusable oil into heavy low-quality oil... In a sense, this exercise is like turning gold into lead.*²⁵³

Matthew Simmons, leading expert on Peak Oil

The Energy Return on Investment (EROI) is the ratio between the useful energy obtained from a source divided by all the direct and indirect energy inputs needed to obtain it. For example, a fuel with an EROI of 10:1 means 10 joules would need to be invested to yield 100 Joules of useful energy, resulting in a net energy (or energy surplus) of 90. If, however, the EROI was 3:1 (in the case of unconventional oil), to net the same 90 Joules around 45 Joules would need to be invested.

As ecological systems with a large energy surplus have a competitive advantage, so does the economy. Indeed, the huge growth in the global economy can be attributed to the switch from low EROI wood (30:1) to coal (80:1) and finally to oil (100:1). Our economy thrives on high EROI energy sources.

Not only is the discovery rate of oil falling, oil production is experiencing diminishing returns. This is clearly illustrated by the evolution of EROI for oil in the US over time.²⁵⁴

1930s, EROI = 100:1

1970s, EROI = 25:1

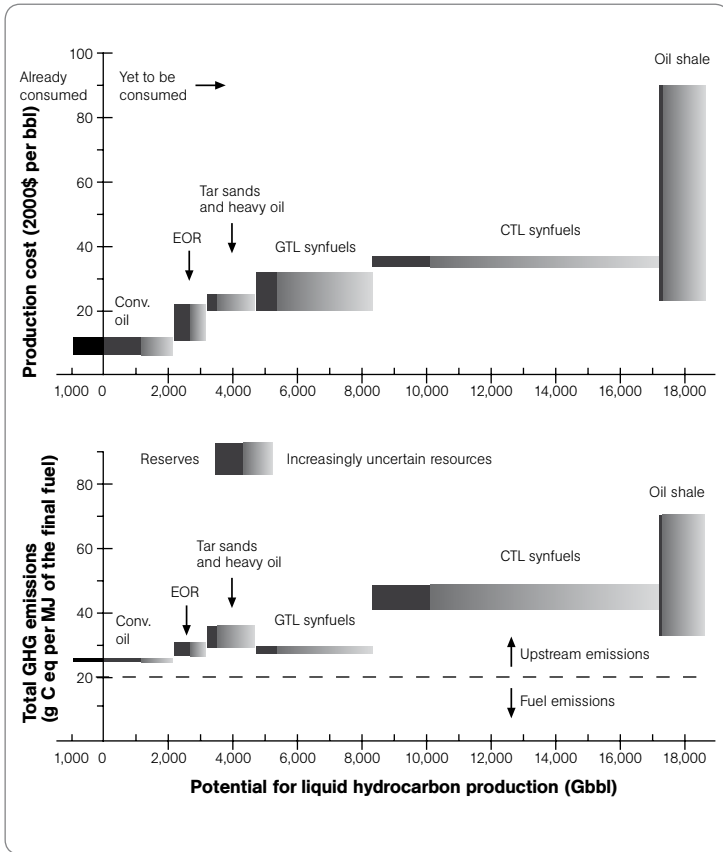
1990s, EROI = 11-18:1

Another study found that the global average EROI for oil in the first half of the 2000s, was approximately 20:1.²⁵⁵ And, if current trends continue the ratio will change to 1:1 in the next 20 to 30 years. In other words, at this point, oil will cease to be a net energy source of energy.

With declining conventional oil reserves, it will be necessary to increasingly rely on *unconventional oil* reserves, such as Canadian tar sands and Venezuela's Orinoco tar belt. Whilst many estimates of the unconventional oil resource indicate that it may well substantially exceed those of conventional oil, increasing amounts of energy will be required to extract that resource.²⁵⁶ Unconventional oil is estimated to have an EROI of around 3:1 – bearing in mind that once EROI approaches a ratio of 2:1, the oil might as well be left in the ground, given the additional energy required to refine it into a useful fuel.²⁵⁷

The techno-optimistic belief holds that when Peak Oil arrives, we will be able to deal with it. This outlook is generally not held by the majority of Peak Oil experts, many of whom hold the view that no combination of existing and emerging technologies will provide industrial nations with the energy necessary to sustain current consumption rates and exorbitant lifestyles.²⁵⁸

Figure 18. Global supply of liquid hydrocarbons from all fossil fuel resources and associated costs in dollars (top) and GHG emissions (bottom). EOR = enhanced oil recovery.²⁵⁹



In the past, higher prices led to increased estimates of conventional oil reserves worldwide, since oil reserves are dependent on price. In other words, reserves are defined as the amount of oil that is considered economically feasible to recover. Geology, however, places an upper limit on what is actually recoverable from conventional oil. Effectively, there is an upper limit to the price of oil – beyond this point additional conventional oil will not be recoverable at any realistic price.

The high price of oil over the past decade has provided an incentive for oil companies to conduct extensive exploration over that period. The results, however, have been disappointing.

Alternatives

What are the potential alternatives to oil if the Peak Oil experts are wrong about a technofix, such as liquid and gas synthetic fuels (synfuels) produced from coal, or the widespread use of biofuels?

Coal has an EROI ratio of around 80:1. Therefore, coal could be transformed into synthetic oil through the Fischer-Tropsch process.²⁶⁰ However, synthetic transport fuels emit even more carbon on a well-to-wheels basis than conventional crude; and when the feedstock is coal, the emissions are double.²⁶¹ Even if the process producing synfuels included CCS, CO₂ emissions would still be greater than those associated with conventional diesel and petrol. According to one study even if 85 per cent of the carbon emitted from the processing of coal were captured (bearing in mind this is the upper limit of what most CCS experts believe is possible), emissions from end-use of these synthetic fuels would produce on average 19-25 per cent as much CO₂ as petroleum derived fuels.²⁶²

Much of the literature focuses on the availability of oil as a result of Peak Oil. But some analysts have raised concerns about the transition from conventionally produced oil, highlighting that synthetic liquid fuels are generally higher capital, higher energy intensive and have higher carbon to hydrogen ratios, and therefore produce more CO₂ than conventional crude oil.²⁶³ Figure 18 shows that the oil transition is not necessarily a shift from abundance to scarcity, but a transition from high quality resources to lower quality resources that have potentially higher levels of environmental damage.

Investment into synthetic fuels will tend to cause world oil prices to fall, benefiting consumers, with potentially the impact of increasing demand even more. Therefore, the management of the oil transition may not be necessarily focused on dealing with global economic collapse, but rather dealing with the environmental problems associated with synthetic liquid fuels derived from other fossil fuels, such as coal and tar sands.

Peak Gas

'Peak gas is an entirely unheard of and unwelcome spectre' ²⁶⁴

Andrew McKillop, energy analyst

Less discussed, but equally real is the prospect for the global peak and decline in the production of natural gas. Peak Gas is analogous to Peak Oil, but refers to the maximum rate of the production of natural gas. For example, in the context of the UK the Digest of UK Energy Statistics reports:

'The UK oil and natural gas production peaked in 1999 and 2000. Since then they have declined at an average rate of 7 per cent per annum (pa) and 3 per cent pa respectively (to 2004).' ²⁶⁵

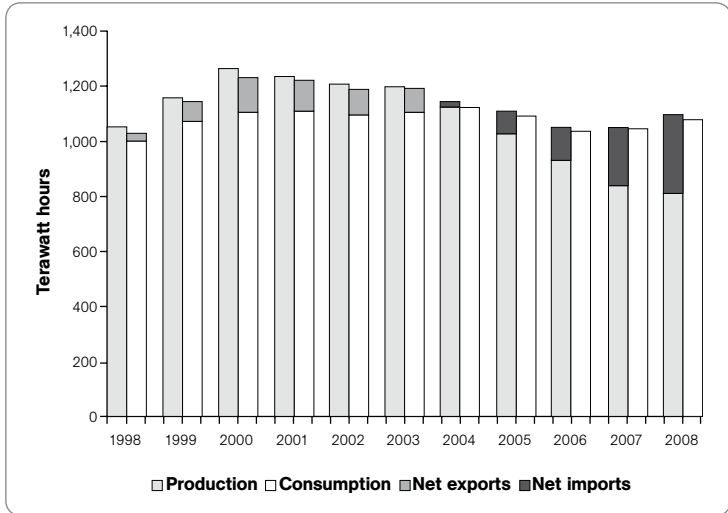
In 2007, Defra reported that emissions from industry in the UK increased during 2006 as power stations had to switch from gas to coal due to high gas prices.²⁶⁶ This implies rising gas prices connected to geopolitics or decline in production could also result in an increase in carbon emissions. Additionally, because a significant proportion of domestic dwellings are dependent on gas for space heating, declining gas supply and subsequent price increases could have a significant impact on fuel poverty.

UK gas fields have already peaked, and it's expected that most of the UK's gas will eventually come from Russia, Iran and Qatar. Figure 19 shows the changes in the UK's indigenous production and consumption of natural gas between 1998 and 2008.²⁶⁷ Since 1998, demand (white) of natural gas shows an inter-annual variability of approximately 5 per cent. At the same time, indigenous gas production showed a slow decline from 2000 (light grey). In 2004, in order to meet demand for the first time since 1997, the UK began importing gas. This reduced the UK's energy independence significantly.

The 'energy dependence' factor is the ratio of net energy imports to demand, and multiplied by 100 to produce a scalable figure. When it becomes 'positive', it means that we are obliged to import energy to meet our demand. In other words, our independence declines. Between 2004, when the UK first lost its energy independence, and 2008, the energy dependence factor has risen almost 5-fold.²⁶⁸

More recently Shell's vice president, John Mills, told delegates at the Abu Dhabi International Petroleum Exhibition and Conference (ADIPEC) on 5 November 2008 that: 'Globally, what people have woken up to is that there is a prospect for the gas industry that its supply-demand crunch could come earlier than anticipated.'²⁶⁹

Figure 19. Natural gas production, net exports/ imports and consumption 1998–2008.²⁷⁰ Consumption plus net exports will differ from production plus net imports because of stock changes, losses and the statistical difference item.



Many energy policies have no concept of Peak Gas being imminent. This is largely due to poor reporting of gas reserves. Whilst estimates of gas reserves succumb to the same problems and lack of accurate disclosure as the oil industry, unlike oil, the gas market is regional.²⁷¹ For example, oil can be transported from the other side of the world for consumption in the UK, but the UK gas market is generally restricted to Europe and Russia. In short, gas is very difficult and expensive to move around, and infrastructure is necessary before a gas reserve can have a market (i.e., storage and pipelines).

If we consider an energy market under Peak Oil/Gas conditions, we would expect the UK to be able to afford to outbid poorer countries in the global oil market. In the Euro-Russian gas market, however outbidding all other equally wealthy European countries would be extremely costly resulting in large increases in gas prices. This suggests that for developed nations like the UK, Peak Gas may pose a greater threat to the economy than Peak Oil, and naturally both will present significant problems to developing nations following a similar carbon intensive development pathway.

Box 19. The feasibility of saving 1 Gt of Carbon by switching to gas

A programme to displace 1400GW of coal-fired power stations with, for example, 1400 1GW 70 per cent fuel efficient CCGT plants, would require an additional 0.7 per cent annual increase in natural gas production on top of the business-as-usual annual increases in demand of 2.3 per cent projected by the IEA.²⁷²

Whilst an additional increase of global gas demand by 0.7 per cent may not seem huge, in the context of known gas reserves and current production from fields, this rate of increase is unlikely to be sustainable for long. For example, gas fields in large developed economies are declining, while regional natural gas constraints are already being observed, primarily in North America (the most intensive consumer of the resource), as well as Russia and Europe.^{273, 274}

Overall, any carbon emissions savings made through fuel switching from coal or oil to gas will be undermined by the onset of Peak Gas. Equally, our assumptions about how gas will be able to carry us through to a low carbon economy are seriously flawed.

For example, in 2006, carbon emissions from British industry covered by the EU ETS (Emissions Trading System) rose by 3.5 per cent during 2006.²⁷⁵ These rising emissions were due to power generators switching from gas to coal in response to high gas prices during 2006. The rise in emissions from these power stations cancelled out all improvements across those sectors that actually reduced their emissions.

Natural gas is also important for many plastics, fabrics, even plastic bags. It provides the heat necessary for cement production, and is also indispensable for making synthetic oils from tar sands (see previous section on Peak Oil).²⁷⁶ Additionally, natural gas is 'absolutely indispensable' for the production of industrial fertiliser.²⁷⁷

Unconventional gas

Unconventional gas is defined by the International Gas Union as: 'methane from tight (very low permeability) formations, methane from coal seams, methane from geopressured brine, methane from biomass (onshore and offshore), and methane from hydrates'.²⁷⁸ But, the fundamental problem with unconventional gas is that its recovery is more energy intensive and expensive compared to oil, and the production process can be much slower. While technology may help to overcome some of these

problems, a very real problem will be transportation, and the significant reduction of the EROI.

Peak Coal?

A scenario seldom discussed is the peaking of coal production. Global consumption of coal is growing rapidly. From 2000 to 2007, world coal extraction grew by a rate of 4.5 per cent compared to 1.06 per cent for oil (oil production actually fell by 0.2 per cent between 2006 and 2007).²⁷⁹ This is opposite to the trend observed over the past two decades. In particular, as China rapidly industrialises, the use of coal is increasing dramatically. In 2005, China was responsible for 36.1 per cent of world coal consumption, the USA 9.6 per cent, and India 7.3 per cent.²⁸⁰

Global coal production is expected to peak around 2025 at 30 per cent above present production in the best-case scenarios. Geographically, coal reserves are concentrated in just a handful of nations. Approximately 85 per cent of global coal reserves are concentrated in six countries (in descending order of reserves): USA, Russia, India, China, Australia, and South Africa. Furthermore, coal consumption generally takes place in the country of extraction – around 85 per cent of coal is used domestically, with around 15 per cent exported.²⁸¹ Again, the concentration of coal in a small number of nations increases energy insecurity.

Coal's contribution to the economy

Currently, coal provides over 25 per cent of the world's primary energy and generates around 40 per cent of electricity. For a number of reasons – including the cost of mining, transport and the lower energy density of coal, and the more inefficient process of electricity generation – its primary energy yield is only around one-third of the economic productivity of the primary energy in oil.²⁸²

While coal may be able to provide some buffer to Peak Oil and Gas, it is one of the most environmentally damaging fossil fuels. For example, while it produces a quarter of the world's energy, it is responsible for almost 40 per cent of the greenhouse gases. Since 1750, the burning of coal has released around 150 gigatonnes of carbon into the atmosphere.²⁸³

Although carbon sequestration could in theory reduce the carbon burden of coal, coal is problematic for other reasons. For example, sulphur, mercury and radioactive elements are released into the air when coals is burned. These are particularly difficult

to capture at source. The mining of coal also destroys landscapes, and very fine coals dust originating in China and containing arsenic and other toxic elements has been detected drifting around the globe in increasing amounts.²⁸⁴

Clean coal?

Clean coal technology refers to some form of CCS but, there is something rather peculiar about the phrase 'clean coal'. Despite the environmental burden from the mining of coal, stick the word clean in front of it, and suddenly it becomes palatable.

In his keynote speech at the Labour Party conference in 2008, the Prime Minister, Gordon Brown, called for a new generation of 'clean coal' plants. Speaking almost simultaneously in the USA, former Vice President and Nobel Prize winner Al Gore stated explicitly: 'Clean coal does not exist.'²⁸⁵

More recently, the Subcommittee on Investigations and Oversight of the US Committee on Science and Technology, which is responsible for overseeing all non-defence research and development programmes at a number of federal agencies published a report examining the recent abandonment of FutureGen by the Department of Energy.²⁸⁶

FutureGen was a 10-year long \$1 billion government/private partnership programme to build a 275MW CCS power plant in Mattoon, Illinois. The report argued: 'Creating 'clean coal' is an extremely complex task involving not only the development of reliable and economical technology to capture CO₂ and other pollutants, and integrating it into electricity-producing coal plants, but also the acceptance of higher electricity prices and unknown liability for carbon dioxide sequestration sites by the public and their elected officials worldwide.' In other words, clean coal is further away than we are being led to believe.

We discuss the potential of 'clean coal' in the context of carbon capture and storage in the following section.

Carbon capture and storage – the nuclear fusion of the 2010s?

*'... carbon sequestration is irresponsibly portrayed as an imminently useful large-scale option for solving the challenge. But to sequester just 25 per cent of CO₂ emitted in 2005 by large stationary sources of the gas [...] we would have to create system whose annual throughput (by volume) would be slightly more than twice that of the world's crude-oil industry, an undertaking that would take many decades to accomplish.'*²⁸⁷

Professor Vaclav Smil (2008)

By 2015, the European Union aims to have 12 large CCS demonstration projects in place, requiring an investment of €5 billion. The expectation is that this development will cause significant cost reductions, making the technology affordable by 2020. There are, however, many drawbacks; for example, it will keep costing large sums of money to make sure the CO₂ stays where it is supposed to, and the process is energy intensive.

CCS – capturing CO₂ and storing it indefinitely – is one of the key technologies expected to contribute to the stabilisation of atmospheric concentrations of CO₂. The IPCC has now endorsed its use, Nicholas Stern concludes that it will be a crucial technology in the 2006 Stern Review, and the UK Climate Policy Programme places significant emphasis on this as a plausible technological response.

Despite this optimism, many still highlight that it is still by no means clear that it will work or that it will become commercially viable in time to have a significant impact on the mitigation of climate change.²⁸⁸ For example, a recent editorial in the journal *Nature Geoscience* argued: 'Capacities for geological storage are uncertain, pilot projects for deep ocean sequestration have been halted, and public acceptance of both options is at best questionable – not least because full risk assessments based on solid scientific data are scarce'.²⁸⁹

A short overview of CCS

CCS can involve a number of different processes which are heavily reliant on advanced and unproven engineering. There are three types of CCS processes currently under consideration. And all three processes are already being applied in several industries on smaller scales, but most without storage.

- **Post-combustion** – the mixture of CO₂ and flue gases after combustion is separated by using a liquid solvent.
- **Pre-combustion** – the fuel is processed prior to combustion resulting in a mixture of mainly CO₂ and hydrogen. Both gas streams are subsequently separated, so that the hydrogen can be combusted for electricity production and the CO₂ for storage.
- **Oxyfuel combustion** – using pure oxygen instead of air when combusting resulting in flue gas that contains mainly water vapour and CO₂. Both streams can easily be separated and treated further if necessary.

According to MIT's Carbon Dioxide Capture and Storage Project Database, there are approximately 40 carbon storage demonstration projects in various scales running at present.²⁹⁰ But CCS is still an experimental technology, or rather a collection of technologies which has yet to be proven at scale. Such optimism in a technology is worrying, particularly as yet, not a single coal plant has been built anywhere in the world that uses complete capture and storage.

The first US pilot plant that can capture CO₂ from coal burning, FutureGen, was due online in 2012. FutureGen began in 2003 by testing safety, permanence and the economic feasibility of storing large volumes of CO₂ in geological structures at 22 test sites. A decision made by the Bush Administration, however, appeared to have stalled the progress of the project.²⁹¹

Disposal of CO₂ under seabeds is still at the research phase according to the IPCC, who also states that pre- and post-combustion capture of the gas has passed research and demonstration stages and is now 'economically feasible under specific conditions'.²⁹²

The cost of CCS

IPCC estimates that installing CCS at a coal-fired power plant could raise the cost of generating power from 4-5 ¢/ kWh to between 6-10 ¢/ kWh. So, CCS could effectively double the cost of electricity from coal at worst and increase the cost by a third at best.

If the captured gas is used for enhanced oil recovery (EOR), revenue could decrease to between 5-8 ¢/ kWh. In the case of EOR, however, whilst CO₂ is being stored deep underground, more fossil fuels are being burned at its expense.

Natural gas can also be used with CCS technology. Gas can be transformed into hydrogen by reacting high temperature steam with natural gas in a process called 'steam methane reformation'. When burned, hydrogen is considered to be a clean fuel and can also be used in fuel cells. The carbon within the natural gas is captured and pumped underground.

How quickly is CCS likely to become commercially viable?

Proponents of CCS claim that 'all technology is proven at the desired scale; we are only demonstrating the ability to integrate technology'.²⁹³ While a number of CCS projects are underway, and have been for some time, there is a plethora of serious concerns about this technology.²⁹⁴ It has been claimed that all the necessary steps required for underground storage of CO₂ have been commercially proven, yet at a recent hearing of the Senate Energy and Natural Resources Committee in 2007, the Director of the US Geological Survey laid out a timeline of commercialisation of workable CCS schemes after 2012.²⁹⁵ He argued that the first commercial deployment would be around 2020, with widespread CCS by 2045.

So what does this mean in terms of emission reduction? One estimate by the Natural Resources Defence Council's Climate Centre suggests that if the total number of new coal plants that analysts think will be built around the world over the next 25 years were built without CCS, these new plants will emit around 30 per cent more CO₂ than all previous human uses of coal.²⁹⁶ But, if the first pilot plant for coal CCS is not going to be online until 2012 – this means the recent trend of increasing carbon intensity of the economy is very likely to continue well into the new decade.

Is CCS the magic bullet?

If artificial carbon storage in the twenty-first century becomes the main route of carbon emission reductions, the total carbon storage by the end of the century could exceed 600Gt.²⁹⁷ Since this may be an unrealistic level of artificial carbon sequestration, in Box 20, we examine the potential implications of capturing 1–3 GtC per year.

Box 20: Achieving emissions reductions through CCS

Assuming a rate of increase in CCS of 70 Sleipner-sized* geological storage formations per year over the next 50 years, providing a total artificial sink capacity of 1 GtC per year would result in the cumulative storage of 27GtC of carbon dioxide by 2050. If this annual carbon capture rate was kept constant over following 50 years until 2100, the cumulative carbon dioxide stored would reach approximately 80 GtC. If this was increased to 3GtC naturally the cumulative carbon stored would be three times this amount (240 GtC).

By capturing this volume of carbon, it is reasonable to assume some leakage would be unavoidable. It would be impossible to detect, monitor and control all potential escape routes of CO₂ for hundreds if not thousands of years – therefore, geological storage cannot be viewed as truly permanent.²⁹⁸

If we consider, on average a 1 per cent global leakage rate from the cumulative reserves, the amount of carbon dioxide leaked from the storage of just 1 GtC per year could, by the end of the century, be of comparable size as the amount of carbon captured and stored (0.8 GtC leaked per annum) – i.e., recapture would be 80 per cent of the emissions captured. Whilst the annual leakage rate of 1 per cent is arbitrary (the IPCC believes that a 99 per cent retention of CO₂ is ‘very likely’ and ‘likely’ over 1,000 years) we must accept that the more carbon dioxide we decide to capture and store in geological reservoirs, the more energy intensive it will be to keep it there, and monitor that it is still there, transferring the responsibility to future generations.

Therefore, artificial carbon sequestration in geological reserves should only be viewed as temporary relief, if at all.

** Sleipner is the first operational carbon reserve. It is located in the North Sea and captures around 0.3 MtC every year.*

Risk of leakage

People often ask; ‘is geological storage [of carbon dioxide] safe’... it’s a very difficult question to answer. Is driving safe... You might say yes or no, but what makes driving something we’re willing to do... You get automakers to build good cars, we have driver training, we don’t let children drive, we have laws against drunk driving-we implement a whole system to ensure that the activity is safe.²⁹⁹

Sally Benson, Executive Director, Global Climate and Energy Project

As journalist Jeff Goodell writes in his book *Big Coal*, tens of thousands of people may be destined to live above a giant bubble of CO₂ and since 'CO₂ is buoyant underground it can migrate through cracks and faults in the earth, pooling in unexpected places.'³⁰⁰ A sudden release of large amounts of CO₂ due to, for example, an earthquake resulting in the fracturing or pipeline failure could result in the immediate death of both people and animals, since asphyxiation can result from inhalation of CO₂ at just a 20 per cent concentration. Because CO₂ is a colourless, odourless and tasteless gas; a large leak would be undetected. An example of just how catastrophic a leak could be is the natural limnic eruption of CO₂ in 1986 from Lake Nyos in Cameroon. The sudden release of 1.6 Mt CO₂ resulted in the asphyxiation of around 1,700 people and 3,500 livestock.

If this rules out the storage of CO₂ in land-based geological sites, let us consider sequestration in ocean saline aquifers, such as Sleipner in Norway. Slow, gradual leakage of CO₂ could result in the dissolution of CO₂ in shallow aquifers, causing the acidification of groundwater and undesirable change in geochemistry (i.e., mobilisation of toxic metals), water quality (leaching of nutrients) and ecosystem health (e.g., pH impacts on organisms).³⁰¹

Transportation of captured carbon could also be problematic. CCS involves a process of converting CO₂ to something else, or moving it somewhere else. Taking the transport of natural gas as an example, we can estimate how secure CO₂ transportation might be. The world's largest gas transport system, 2,400km long running through Russia (the Russian gas transport system), is estimated to lose around 1.4 per cent (a range of 1.0–2.5 per cent).³⁰² This is comparable to the amount of methane lost from US pipelines (1.5 ± 0.5 per cent). Therefore, it is reasonable to assume that CO₂ leakage from transport through pipelines could be in the order of 1.5 per cent. Furthermore, it is noteworthy that around 9 per cent of all natural gas extracted is lost in the process of extraction, distribution and storage.

Storage capacity

A detailed analysis (rather than an estimate) of known US geological sequestration sites undertaken by the US Department of Energy revealed that only 3GtC could be stored in abandoned oil and gas fields.³⁰³ This estimate, however, does exclude saline aquifers (very little is known about potential US saline aquifers).

Assuming that the USA took responsibility for CO₂ emissions that were directly proportional to its share of global emissions, the USA's capacity to store its own carbon

in known geological sequestration sites would be exhausted in 12 years. Similarly, a recent analysis explored the potential storage capacity in Europe. The study found that based on Europe's current annual emission rate of 4.1 GtCO₂ per year in the EU 25, the medium-range estimate of storage capacity is only 20 times this.³⁰⁴ In other words, CCS is clearly not a long-term solution, as 'peak storage' could be reached relatively quickly.

Further sequestration would require expensive and potentially unsafe pipelines directing CO₂ to sequestration sites further a field. This would be an energy-intensive process which is why CCS not only poses significant future risks in terms of leakage, but also reduces the net energy gained from a particular fuel – what has been called the 'energy penalty'.³⁰⁵ Given these problems, to put such faith in schemes which are operationally immature, instead of decreasing our carbon emissions, seems outrageously risky. Surely it would be better not to produce the emissions in the first place?

One further limitation of CCS is that, only one-third of emissions in industrialised countries are actually produced in fossil-fuelled power stations. A significant proportion comes from the transport sector (around 30 per cent), and as yet CCS has only been developed for static CO₂ sources.

By pursuing a CCS pathway, we are encouraging our continued reliance on fossil fuels delivering energy through a centralised system. Should CCS become economically viable, it could act to undermine initiatives to move towards a more efficient distributed energy system with diverse arrays of low carbon energy sources.

Could CCS be another 'just around the corner' technology like nuclear fusion? Will small-scale pilot projects ever realistically be scaled up to make a significant impact on ever growing global emissions?

For over 50 years, physicists have been promising that power from nuclear fusion (see Box 21) is on the horizon. While fusion has been achieved, in the JET (Joint European Torus) reactor, the experimental reactor did not break even, i.e., it consumed more energy than it generated, but managed to produce 16MW of energy for a few seconds. In a *Nature* news feature, science journalist Geoff Brumfiel commented that '... the non-appearance [of nuclear fusion] should give us some insight into how attempts to predict the future can go wrong'.³⁰⁶

The limits to nuclear

*'So the big question about nuclear 'revival' isn't just who'd pay for such a turkey, but also... why bother? Why keep on distorting markets and biasing choices to divert scarce resources from the winners to the loser – a far slower, costlier, harder, and riskier niche product – and paying a premium to incur its many problems? Nuclear advocates try to reverse the burden of proof by claiming it's the portfolio of non-nuclear alternatives that has an unacceptably greater risk of non-adoption, but actual market behaviour suggests otherwise.'*³⁰⁷

Amory Lovins, Chief Scientist, Rocky Mountain Institute

nef's 2005 report *Mirage and Oasis*, made the case that nuclear power faced insurmountable problems in living up to expectations placed upon the sector to help deliver both energy security and an answer to climate change.³⁰⁸ The report made the case that, if anything, an expanding nuclear programme would increase insecurity and, by distracting skills and other resources, delay more effective solutions.

In his book – *The lean guide to nuclear energy: a life-cycle in trouble* – David Fleming introduces the term 'energy bankruptcy', referring to a point in the nuclear energy life cycle where more energy is used in the life cycle than can be supplied as electricity.³⁰⁹ Fleming illustrates that whilst emissions of CO₂ from nuclear energy superficially look 'rather good' at approximately 60g/kWh (cf. 190g/kWh for natural gas), scratch the surface and it becomes very clear that this comparison is very misleading.

Fleming identifies that the long-term disposal solution for nuclear waste has been deferred, resulting in a 'back log' of emissions neither realised nor accounted for yet. Not only will we eventually have to face the challenge of a long-term storage solution of nuclear waste, which will be a very energy-intensive process due to the necessary over-engineering to safeguard future generations from the hazardous waste, but emissions from nuclear energy will grow relentlessly as uranium ores used progressively turn to low-grade.

Box 21. Nuclear fusion

Nuclear fusion is technology that produces energy by mimicking the Sun. The fusion of two hydrogen nuclei (a hydrogen atom stripped of its electron) results in the formation of a single Helium nucleus. Since the mass of a single helium nucleus is less than the combined masses of the two hydrogen nuclei, energy is released based on Einstein's mass-energy equivalence formula $E = mc^2$. Initiating the process of fusion requires extremely high temperatures (hundreds of millions of °C), as the positively charged nuclei need to overcome their natural repulsion. This can only be achieved when the nuclei are moving very fast or are closely packed together. As has often been commented, any practical, large-scale application of fusion technology remains decades away, as it has done for decades.

The hydrogen economy

It is often argued that the next evolutionary step in the global energy system is the substitution of natural gas with hydrogen – often assumed to be a zero-carbon fuel. Whilst this is true at the point of end use, it ignores carbon embedded within the fuel.

Hydrogen itself is not a source of energy, but a carrier. Because of this, hydrogen first has to be produced from the reaction between carbon monoxide (CO) and methanol, through steam reactions (steam reformation) with natural gas, oil or even coal or by the electrolysis of water (efficiencies of fuel cells and hydrogen production are discussed later). But there are two problems here.

Hydrogen will only be truly zero carbon if it is produced through zero-carbon electricity generation. A life-cycle assessment by the National Renewable Energy Laboratory estimates the carbon emissions associated with hydrogen production from the steam reformation of natural gas without CCS, would equal just under 12kg of CO₂e for every kg of H₂ – one kg of H₂ has a similar energy content to 3m³ of natural gas, or the same amount of energy required to drive a 2003 Golf Edition approximately 30km.³¹⁰

A hydrogen economy, promoted as a zero-carbon energy source, based on the energy system we have at present (i.e., dominance of fossil fuels) relies heavily on the assumption that CCS is safe and secure. And, we have already argued that CCS is by no means guaranteed to work, and there are limited gas reserves.

Other alternatives to steam reforming include the electrolysis of water into hydrogen by using a renewable energy source, such as wind. Yet the process of electrolysing water to hydrogen, and then burning it as a clean fuel to use in a fuel cell to produce electricity introduces two additional inefficiencies. Why introduce these inefficiencies if there is zero-carbon electricity generation in the first place? Secondly transportation of hydrogen is expensive (both cost and energy).³¹¹

Whilst hydrogen may become an effective way of storing energy from renewables to cope with intermittency of electricity supply from renewables, such as wave, solar and wind (an issue often raised by those not in favour of renewable energy), it doesn't seem likely that the hydrogen economy will be upon us any time soon.

Box 22: Hydrogen economy for the UK's transport system: is it possible?³¹²

If we decided to run Britain's road transport system, say, on cleanly produced hydrogen – electrolysing water using non-CO₂-emitting forms of generation – our options would be:

- solar array covering every inch of Norfolk and Derbyshire combined;
- a wind farm bigger than the entire southwest region of England.

All very well, but we'd also need space for renewable energy technology for use in our homes, offices and industries.

Biofuels

*Whilst, biofuels can be produced sustainably and with real CO₂ reductions ... in the industrialised world there simply isn't the land.*³¹³

David Strahan, author of *The Last Oil Shock* (2007)

Concern for climate change and the rising price of oil has resulted in new policies that aim to substitute petrol and diesel with biofuels.³¹⁴ There are, however, a number of unintended consequences of the agro-industrial scaling out biofuels.

Last year the impact of the US's significant drive for increasing production of bioethanol had a significant impact on the food market because of the diversion of cereals, specifically Maize away from animal feed.³¹⁵ For example, in its *2008 World Development Report*, The World Bank stated:

*'Biofuel production has pushed up feedstock prices. The clearest example is maize, whose price rose by over 60 per cent from 2005 to 2007, largely because of the US ethanol program [sic] combined with reduced stocks in major exporting countries. Feedstock supplies are likely to remain constrained in the near term.'*³¹⁶

The report then goes on to state:

'The grain required to fill the tank of a sports utility vehicle with ethanol ... could feed one person for a year; this shows how food and fuel compete. Rising prices of staple crops can cause significant welfare losses for the poor, most of whom are net buyers of staple crops'

In other words, the rise in popularity of biofuels is creating competition for land and water between crops grown for food and those grown to make biofuels. This has led to civil unrest around the world. For example, the 'Tortilla Riots' in Mexico in 2007 followed the dramatic rise in price of corn (a staple food for poor households) as more land was given over for biofuel production. The impact of biofuel production on food security is discussed in more detail in the next section.

In terms of climate change, new calculations looking at the full lifecycle of palm oil production concluded that under a range of fairly typical circumstances vastly more

carbon was released into the atmosphere as a result of growing palm oil, than results from burning fossil fuels.³¹⁷ In the context of bioethanol, research has also shown that biofuels produced from corn, wheat or barley all contain less energy than the energy required to produce them.³¹⁸

Research published earlier in 2007 showed that the growth of palm oil for biodiesel for the European market is now the main cause of deforestation in Indonesia.³¹⁹ Because of deforestation and drainage of peat-lands necessary to grow the crop, every tonne of palm oil created in South East Asia resulted in up to 33 tonnes of carbon dioxide emissions – ten times as much as conventional petroleum. In 2006, the UK imported 1.6 million tonnes of palm oil and palm kernel oil, 676,972 tonnes of which was imported from South East Asia. Separately, an estimate by a coalition of aid and environment groups including Greenpeace, Oxfam, the RSPB, WWF and Friends of the Earth, suggests that soya grown for biodiesel grown on deforested land would take 200 years before it could be considered carbon neutral.³²⁰

In light of the seemingly unsustainable nature of biofuels, in 2008 the UK government commissioned Edward Gallagher to examine the indirect impact of biofuels on climate change and food security.³²¹ The review confirmed growing concerns of the negative impacts of UK and EU biofuels policy on land use, greenhouse gas emissions and food security. In light of the review, the UK government has agreed to reconsider its policy on biofuels.

Box 23: Is the complete or even partial substitution of diesel and petrol fuels with biofuels possible?

- If the UK directly substituted all its diesel and petrol fuels (by energy not volume) to rapeseed oil biodiesel and corn bioethanol, the amount of agricultural land required would be approximately 36 million hectares. To put this figure in context, the total land area in the UK is just over 24 million hectares. Furthermore, less than 20 per cent of the UK's land is suitable for agriculture.
- To meet President Bush's goal of increasing bioethanol production from the five billion gallons currently produced to 35 billion gallons by 2017 would require more corn than the USA currently produces.³²²
- To replace 10 per cent of global petrol production with bioethanol, Brazil would have to increase its ethanol production by a factor of 40, and would result in the destruction of around 35 per cent of the remaining Amazon Rainforest.
- By increasing the consumption of bioethanol to around 34 million barrels per year by 2050, 1GtC of carbon could be offset, due to the substitution of mineral liquid fuels.³²³ We find, however, that coupled to population growth; this would require a 25 per cent increase in cultivated land by 2050. This will clearly mean claiming a vast amount of land from the already stressed natural environment

Geoengineering – technological saviour or damaging distraction?

'There is a suspicion, and I have that suspicion myself, that a large number of people who label themselves "green" are actually keen to take us back to the 18th or even the 17th century. [Their argument is] "Let's get away from all the technological gizmos and developments of the 20th century"... And I think that is utter hopelessness ... What I'm looking for are technological solutions to a technologically driven problem, so the last thing we must do is eschew technology.'

Professor Sir David King, former
Chief Scientific Advisor to the UK government³²⁴

As we have shown earlier in this report, even modest changes to the work-and-spend lifestyle of the global North would be hugely beneficial, yet David King's comments imply that the political consensus is that changes in lifestyle should not be necessary and would be largely unwelcome. As a result more novel solutions to climate change are beginning to receive more and more interest.

Once an idea limited to the realms of a James Bond film, human manipulation of climate – geoengineering – is increasingly being discussed by some of the most respected climate scientists in the world. From giant mirrors in space reflecting sunlight away from Earth, to pumping aerosols into the stratosphere, or large-scale cloud-seeding (releasing aerosols in the lower atmosphere is thought to initiate the formation of clouds), geoengineering could, in the not too distant future, become a reality.

In its current context,³²⁵ geoengineering technologies can be divided into two categories: those that remove greenhouse gases from the atmosphere, and those that reduce incoming solar radiation – with the intention of offsetting the changes to Earth's radiation budget caused by anthropogenic greenhouse gases. The debate about the role geoengineering can and should play in dealing with the impacts resulting from climate change is one which is already beginning to gain momentum.³²⁶

In most cases, geoengineering schemes are viewed as a stopgap between now and some point in the future where mitigation technology is cheaper and more widespread.

There are, however, large technical and scientific uncertainties. For example Professor David Victor, Director of the Laboratory on International Law and Regulation at Stanford University argues: ‘...real-world geoengineering will be a lot more complex and expensive than currently thought because simple interventions—such as putting reflective particles in the stratosphere—will be combined with many other costlier interventions to offset nasty side effects.’³²⁷

The large majority of academics working in the field of geoengineering research have been clear that their research and technical propositions are not intended to distract from the efforts of reducing greenhouse gas emissions as the first priority for controlling climate change. However, many now argue that a technological intervention may be required parallel to current mitigation efforts.³²⁸

The Royal Society’s recent report *Geoengineering the climate: Science, governance and uncertainty* assessed both technical and social aspects of geoengineering options.³²⁹ With respect to the technical level, two approaches are identified: Carbon Dioxide Removal (CDR) techniques and Solar Radiation Management (SRM) techniques.

The objective of CDR methods is to remove CO₂ from the atmosphere by: enhancing uptake and storage by terrestrial biological systems, enhancing uptake and storage of oceanic biological systems or using engineered systems (physical, chemical, biochemical). In contrast to this, SRM techniques focus on changing the Earth’s radiation budget by reducing shortwave radiation absorbed by the Earth. Both techniques have the ultimate aim of reducing global temperatures, however they differ in their modes of action, timescales over which they work, and costs. There is a general preference towards CDR methods as a way to augment continuing mitigation action in the long term, whilst SRM could provide short-term back-up for rapid reduction in global temperatures.³³⁰

Of the two techniques, The Royal Society report found SRM to have the least potential. This is due to high levels of uncertainty associated with large-scale modification of the climate. In particular, climate scientists have raised concerns about the potential impact SRM may have on rainfall patterns.³³¹ While temperatures may return to those of the pre-industrial era, rainfall patterns would not.³³² There is also particular concern about the impact of SRM interventions on the Asian and African summer monsoons on which billions depend.³³³ Furthermore, beyond non-invasive laboratory/computer modelling and analogue case studies – the first phase of research and development of SRM technologies – research would necessarily involve intentional interventions

with the climate system. Because it is a technology with many uncertainties, field experiments beyond limited duration, magnitude and spatial-scale could involve some risk of unintended climate consequences. Yet, the collection of direct empirical evidence from large-scale field experiments would be a necessary part of any research programme.³³⁴

Researchers have also highlighted that should any SRM intervention stop abruptly or fail, global temperatures could rise rapidly.³³⁵ As the concentration of CO₂ in the atmosphere increases, carbon sinks would be weakened with possible carbon-cycle feedbacks accelerating the increase in CO₂ concentration in the atmosphere. Termination of the climate modulation provided by a geoengineering scheme, could result in a temperature change of 2–4°C per decade (there is no evidence that global temperature changes have approached this rate at any time over the last several glacial cycles).³³⁶ This rate of temperature change is 20 times faster than the rate predicted under a business-as-usual scenario. Clearly such a rapid change in climate would have devastating impacts on humans and the environment.

The Royal Society's viewed CDR as having the most potential and as some mimic natural processes (e.g. ecosystem-based CDR and some engineered CDR) they may involve fewer risks compared to SRM. However, this category of geoengineering is likely to be less effective in reducing global temperatures quickly.

Both CDR and SRM are relatively under researched technologies.³³⁷ Specifically with respect to SRM, there has been limited consideration in these proposals on the impact of continued increases in CO₂ – this is the most worrying. For example, the direct effect of elevated CO₂ could have significant effects on the hydrological cycle. For example, a recent modelling study showed that in the absence of climate warming and with elevated CO₂, changes to plant water use efficiency resulted in a decrease in precipitation over vegetated areas in the Tropics.³³⁸

However, one of the most critical reasons for making absolute cuts in CO₂ emissions is due to acidification of ocean waters.³³⁹ As CO₂ is absorbed by the oceans, it forms a weak acid, called carbonic acid. Part of this acidity is neutralised by the buffering effect of seawater, but the overall impact is to increase the acidity. According to a report by the Royal Society, apart from global climate change, this should be the second largest motivation for reducing CO₂ emissions.³⁴⁰ So far, the acidity of the ocean surface has increased by 0.1 units. General circulation models show that if CO₂ emissions from fossil fuels continue to rise, a reduction of 0.77 units could occur by 2300.

To put this in perspective, over the past 300 million years, there is no evidence that the pH of the ocean has ever declined by more than 0.6 units. While there is limited research into the impact of pH decline on marine biota, organisms which have calcium carbonate skeletons or shells, such as molluscs, coral and calcareous plankton, may be particularly affected, especially as a large proportion of marine life resides in surface water.³⁴¹

Given that techniques for reducing acidity are unproven on a large scale and could have additional negative impacts on the marine environment, it is clear that a technical solution that only partially deals with controlling the climate will not address anthropogenic interference of the carbon-cycle.

Whilst none of the current geoengineering methods currently offer immediate solutions to the problems of climate change, nor do they replace the need to continually reduce emissions- a growing group of academics now argue that they could be a potential option to actively engineer the climate on a planetary-scale to curb and control the impacts associated with a global temperature rise of 2°C or more.

Although our understanding of the climate system continues to improve, and the forecasting skill of climate models improves, there is still no guarantee that we'd be able to predict the implications of manipulating the delicate energy balance of the climate system that has already been hurled out of equilibrium.

As well as the technical feasibility of geoengineering, its application must also be socially and ethically permissible. The unknown factors associated with manipulating climate change heighten the need for any decisions to be mutually agreed upon and accepted. The language of 'risk' cannot be disassociated from this debate as the changes created by geoengineering, may, in the long term be irreversible. So, if the effects of geoengineering were to be irreversible, then those who made the decision to undertake these technologies would be choosing one climate path for future generations rather than another.^{342, 343}

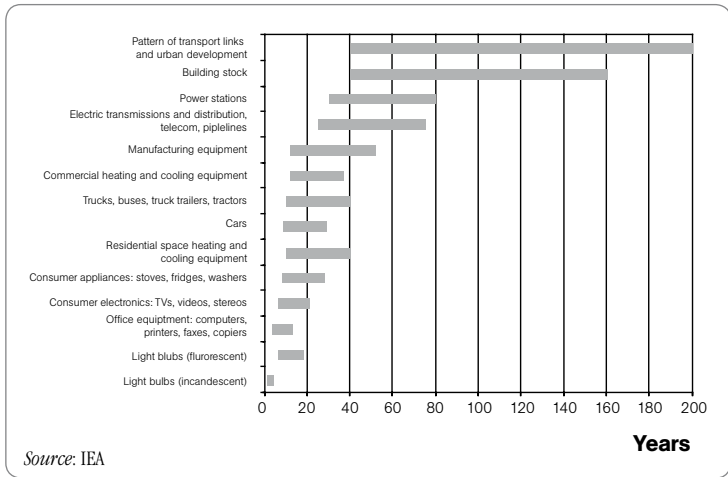
How much can energy efficiency really improve?

One hundred years ago, electricity production, at best was only 5–10 per cent efficient. For every unit of fuel used, between 0.05 and 0.1 units of electricity were produced. Today, the global average efficiency for electricity generation is approaching 35 per cent and has remained largely unchanged for the past 40 years.³⁴⁴ This may come as a surprise given the often-held view that technology has continued to improve ϵ_{ss} and will continue to do so in the future. Whilst this is largely due to the current mix of the global energy system, rather than individual technologies, it highlights two problems associated with the assumption that we can expect a steady increase in energy efficiency/decline in carbon intensity of the global economy. First, as a general rule of thumb, in a given technology class, efficiency normally starts low, grows for decades to centuries and levels-off at some fraction of its theoretical peak.³⁴⁵ As described earlier in the report, the second law of thermodynamics, is one of the most fundamental physical laws; it states that energy conversion always involves dissipative losses (an increase in entropy). As such, any conversion can never be 100 per cent efficient.

The results of our analyses have shown, future stabilisation pathways are dependent on assumptions about energy intensity and, therefore, energy efficiency. These assumptions fail to acknowledge, however, that in many cases of ϵ_{ss} , engineers have already expended considerable effort to increase the energy efficiency.³⁴⁶

Second, we are built into and are still building ourselves into a centralised energy system. Such systems favour fossil and nuclear fuels over renewable energy, do not exploit the maximum efficiency possible (i.e., do not favour a system where an exergy cascade, such as combined heat and power, can be utilised), and the energy system is subject to large distribution losses. This is likely to continue into the future if energy policies rely heavily on nuclear and CCS schemes. Particularly given that CCS reduces the efficiency of the energy system, and nuclear fission is a mature technology, already approaching its efficiency limit, and is far from being carbon neutral, as is often claimed. If nuclear fusion ever becomes a viable option, it is likely to have the same thermal efficiencies as nuclear fission.³⁴⁷ In other words, many of the technologies that make up the global energy system are mature technologies and their current efficiencies are at or almost at their practical maximums.

Figure 20: Average lifespans for selected energy/related capital stock³⁴⁸



The slow capital stock turnover for large energy infrastructure – shown in Figure 24 also means that energy decisions made now will influence the trajectory of emissions over the next 25–60 years, with obvious implications for the speed at which a transition to a low carbon economy can take place.

Amongst the most efficient technologies are large electric generators (98–99 per cent efficient) and motors (90–97 per cent). This is followed by rotating heat engines that are limited by the Carnot efficiency limits (35–50 per cent), diesel (30–35 per cent) and internal combustion engines (15–25 per cent). Improvements in these areas are, therefore, small. In fact, the energy efficiency of steam boilers and electrical generators has been close to maximum efficiency for more than half a century.³⁴⁹ Similarly, the most efficient domestic hot water and home heating systems have been close to maximum efficiency for a few decades.³⁵⁰

Whilst hydrogen fuel cells are often pursued as future sources of ‘clean, zero-carbon, highly efficient sources of energy’, there are also upper limits to the energy efficiency achievable. Fuel cells are currently 50–55 per cent efficient, and are believed to reach a maximum at around 70 per cent. This is due to limits imposed by electrolytes, electrode materials and catalysts within the fuel cell system. Additionally the production of hydrogen from oil or methanol is has a maximum efficiency of 75–80 per cent.³⁵¹

Growth isn't possible

In terms of renewable energy, photovoltaic (PV) cells currently have efficiencies between 15 and 20 per cent (in commercial arrays) with a theoretical peak of around 24 per cent (highest recorded efficiency = 24.7 per cent). This maximum is higher for multi-band cells and lower for more cost-effective amorphous thin films. Wind turbines have commercial limits around 30–40 per cent, with a maximum efficiency limit of 59.6 per cent – the Betz limit.³⁵² Hydroelectric power is already at its maximum average efficiency of around 85 per cent.³⁵³

Photosynthesis is highly inefficient in converting sunlight into chemical energy with the most productive ecosystems being around 1–2 per cent efficient and a theoretical peak of around 8 per cent. The extent of bioenergy is also restricted by the volume of biomass necessary versus land available which is possibly not greater than 30 per cent of the Earth's land-surface.

In the case of lighting, high pressure sodium vapour has an energy efficiency of around 15–20 per cent, whilst fluorescent (10–12 per cent) and incandescent (2–5 per cent) illumination generate more heat than light.

For transport systems, specifically road transport, improvements in private vehicle efficiencies are largely due to vehicle mass (see Box 9), driving patterns and aerodynamic drag and the use of technology such as regenerative braking (electric power recovery from mechanical energy otherwise lost). The efficiency of the internal combustion and diesel engine are largely at their maximum. Further improvements could be made by hybrid, electric (dependent on the central power plant efficiency) or fuel cell vehicles. Box 24 shows a similar levelling of in aviation efficiency gains.

Box 24. Aviation eating up efficiency gains

Some are optimistic that technological improvements will allow air travel to continue to grow into the future while keeping emissions under control – and eventually reducing them overall. This kind of optimism was embodied by the strap line that heralded the new Airbus A380 on its maiden flight from Singapore to Sydney in 2007: ‘cleaner, greener, quieter, smarter’.

Overall fuel efficiency gains of 70 per cent between 1960 and 2000 are often cited as evidence for continued improvements in efficiency. For example, the Air Transport Action Group has said: ‘Building on its impressive environmental record, which includes a 70 per cent reduction in . . . emissions at source during the past 40 years, the aviation industry reaffirmed its commitment to . . . further develop and use technologies and operational procedures aimed at minimising noise, fuel consumption and emissions.’³⁵⁴

There is little evidence, however, that major improvements will be made in the near future. Despite technological achievements so far, absolute growth in fuel use by aircraft has grown by at least 3 per cent per year.³⁵⁵ Quite simply, the efficiency improvements of 0.5 to 1.3 per cent a year that have been achieved are being dwarfed by the industry’s annual growth of 5–6 per cent.³⁵⁶ The time it takes to pension off and replace commercial aircraft is long, and any additional efficiency gains anticipated are likely to be wiped out by a continuing increase in flights.³⁵⁷

The Advisory Council for Aeronautics Research in Europe (ACARE) has established ambitious goals for improvements to aircraft efficiency. By 2020, it wants the industry to achieve a 50 per cent reduction in CO₂ per passenger kilometre. Of this, 15–20 per cent will be from improvements to engines, 20–25 per cent from airframe improvements and a further 5–10 per cent from air traffic management.³⁵⁸ But to achieve these targets, the industry would need to improve its efficiency by over 2.5 per cent per year. In reality, efficiency gains of just 1 per cent have been described as ‘rather optimistic’ given that the jet engine is now regarded as mature technology, and annual efficiency improvements are already falling.³⁵⁹

An analysis of projected aviation growth and anticipated improvements in aircraft efficiency suggests that if growth in Europe continues at 5 per cent,

traffic will double by 2020 (relative to 2005). With an 'ambitious' 1 per cent annual improvement in fleet efficiency, CO₂ emissions would rise by 60 per cent by 2020 (and 79 per cent if emission trading did not affect growth). Even if a 10 per cent reduction in CO₂ per passenger kilometre were to be achieved, CO₂ emissions would rise by 45 per cent.³⁶⁰

Figure 21 shows long-haul aircraft efficiency gains since 1950 as an index based on the De Havilland DH106 Comet 4 (the least efficient long-haul jet airliner that ever flew). It shows a sharp improvement in efficiency between 1960 and 1980 but a steady slowing of efficiency gains since then. Further efficiency gains between 2000 and 2040 are likely to be in the order of 20–25 per cent.³⁶¹ Even the performance of the new Airbus A380 fits neatly into the regression, indicating that the 50 per cent more efficient aircraft that some have predicted by 2020 are highly unlikely.

Figure 21. Long-haul aircraft efficiency gains since 1950 as an index based on the De Havilland DH106 Comet 4.³⁶²

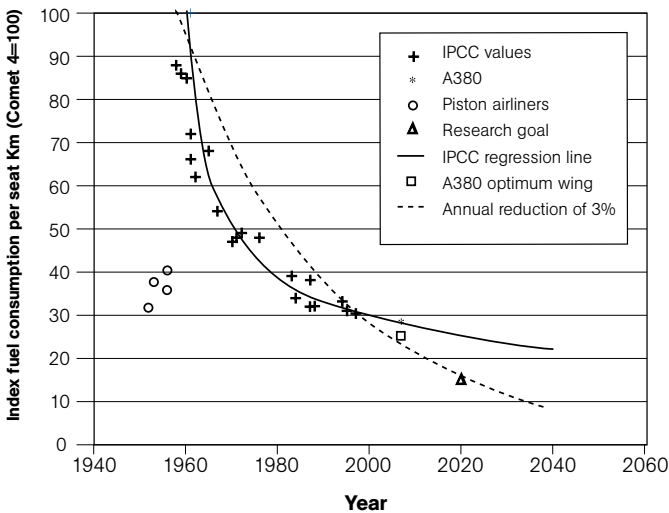
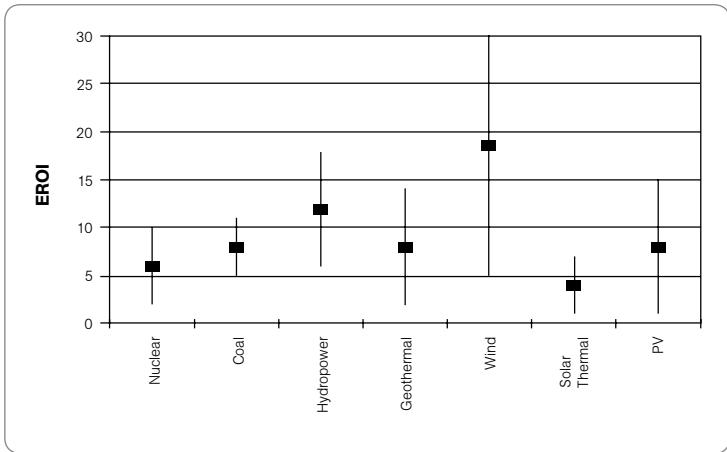


Figure 22. EROI for various electric power generators.³⁶³



One way of comparing efficiencies of different technologies is through an EROI assessment. Figure 22 shows various EROI ratios for a number of electric power generators. It shows that wind turbines compares favourably with other power generation systems. Base load coal-fired power generation has an EROI between 5 and 10:1. Nuclear power is probably no greater than 5:1, although there is considerable debate regarding how to calculate its EROI. The EROI for hydropower probably exceeds 10, but in most places in the world the most favourable sites have already been developed.

Practical limitations to the improvements in supply-side energy efficiency

*An increase in resource efficiencies alone leads to nothing, unless it goes hand in hand with an intelligent restraint of growth.*³⁶⁴

Wolfgang Sachs (1999)

In terms of work generation from a heat engine (where heat is converted to work), the Carnot efficiency, named after the French Physicist Nicolas Léonard Sadi Carnot, determines the maximum efficiency in which this can be achieved.

The thermal efficiency of gas and steam turbines is a function of the temperature difference between the inlet temperature and the outlet temperature. In a perfect Carnot cycle, the maximum efficiency that can be achieved is around 85 per cent. In

reality, the most efficient combined-cycle gas turbine (CCGT) plants have efficiencies in the range of 59–61 per cent. In a CCGT, gas is used to drive a turbine and the exhaust gases are used to raise steam to drive a second turbine. The high efficiency of this type of turbine is due to the use of both the gas and the 'waste' exhaust gases. Currently, however, the average fossil-fuelled power plant is approximately 33 per cent efficient.³⁶⁵ With the potentially imminent peaking in production of gas, it seems unlikely this will change significantly in the future.

An Integrated Gasification Combined Cycle (IGCC), is a similar technology to CCGT, but uses coal as a feedstock. Coal is converted into a synthetic gas and then used in a CCGT. The efficiency of an IGCC is in the range of 30–45 per cent. Obviously, without CCS, this process would act to increase the carbon intensity of the economy, but with CCS the efficiency of the plant declines. Biomass could be used as a feedstock however, which would have a significant impact on carbon emissions.

Fuel cell technology converts the chemical energy of fuels directly (electrochemically rather than through combustion) and therefore, is not restricted by the Carnot efficiency limit. Therefore, considerably higher efficiencies can be met. There are a number of different types of fuel cells entering the market. Generally all fuel cells run on hydrogen, although some can run on fuels such as CO, methanol, natural gas or even coal if externally converted to hydrogen.³⁶⁶ The advantage of fuel cells is that emissions at point of use are simply water vapour and therefore could significantly contribute to a reduction in urban pollution. But, as described earlier in the report, hydrogen is not a fuel; it is a carrier of energy. And, if the hydrogen is produced from a hydrocarbon fuel, then the benefits as a low carbon solution are reduced. Furthermore, scaled up significantly, fuel cell technology will hit other limiting factors, such as the availability of the metal platinum – a catalyst in the fuel cell.

It is useful at this point to return to the term 'exergy'. This describes the maximum useful work obtainable from an energy system at a given state in a specified environment.

By and large, any attempt to increase the overall efficiency of a supply-side energy process could be achieved by making use of low exergy products as well as high exergy products of energy generation. An example of this is CCGT (described above) or a combined heat and power station (co-generation). Co-generation involves the recovery of thermal energy that is normally lost or wasted. Both electricity and the low-grade waste heat are used for both powering appliances and heating. By adding district heating capacity to a CCGT, efficiency can increase to almost 80 per cent.

Distributed generation?

An area that is strongly associated with efficiency of the energy industry is distributed generation. While its main benefits are cleaner and more efficient generation and location of generation closer to demand, distributed generation also has an effect on losses. In simple terms, locating generation closer to demand will reduce distribution losses as the distance electricity is transported will be shortened, the number of voltage transformation levels this electricity undergoes is lessened and the freed capacity will reduce utilisation levels.³⁶⁷

Ofgem (2003)

Using an economic model developed by the World Alliance for Decentralised Energy (WADE),³⁶⁸ it has been repeatedly shown that the pursuit of a decentralised renewable energy system with cogeneration is becoming increasingly economically attractive; not only for mitigating climate change, but also in the face of dwindling fossil fuel reserves.³⁶⁹

Centralised energy systems, such as the UK's on average lose 9.3 per cent (global average is 7.5 per cent) of all electricity generated through transmission and distribution losses.³⁷⁰ Ofgem estimated that the UK could achieve approximately 4 per cent of the UK government's domestic target of a 20 per cent reduction in CO₂e by 2010 through simply reducing distribution losses by 1 per cent. When these distribution losses are considered, the argument against a new nuclear age or large-scale CCS is strengthened further.

Distributed energy is a favourable pathway for developing nations. This is because a centralised energy system using a transmission network like the National Grid requires a high capital transmission and distribution network. Once in place, the network will also have high operation and maintenance costs as well as significant energy losses.

The challenges to decentralised energy are fourfold, however:

- 1 Policy and regulatory barriers to decentralised energy.
- 2 Lack of awareness and effectiveness of decentralised energy.
- 3 Failure of industrial end-users to accept and adapt to decentralised energy agenda.

- 4 Concerns regarding the dependence of decentralised/cogeneration of fossil fuels. Indeed, the decentralised system proposed by Ken Livingstone, is based on combined heat and power from CCGT.

Cogeneration lends itself to specific types of generation, generally small scale (less efficient), close to where the low-grade heat can be used. This, therefore excludes nuclear. It is also difficult to obtain large and/or consistent benefits from cogeneration, since the normally lost or waste heat cannot be stored until needed. Thus, it is necessary to try to balance the amount and timing of the loads between electricity generation and heat utilization.³⁷¹

Given this, 'cogeneration is likely to remain a relatively minor contributor to improved energy efficiency.'³⁷² Nevertheless, a decentralised energy system is still more efficient in terms of transmission and distribution losses.

The absolute theoretical efficiency that can be achieved assumes that energy operations experience no losses. It is estimated that ϵ_{ss} is currently 37 per cent at the global level and that a two-fold increase may be possible, i.e., a 200 per cent improvement in ϵ_{ss} .³⁷³ But the assumption that the types of technology that could lead to such a significant change will become commercially available and installed at a rate concomitant with within the timescales necessary to stabilise greenhouse gas concentrations at a 'safe level' is questionable.

Whilst the limits of thermodynamics only apply to the heat engine (thermal) generation of electricity, there are also theoretical and practical limits to the use of renewable energy, also based on the second law of thermodynamics.

The limits to a renewable energy fix

There are numerous reasons for a rapid transition to a global energy system based on renewable technologies: wind, water and solar. As described throughout this report, these include climate change, energy security in the face of Peak Oil, cost-effective conversion and flexible and secure supply. Several studies have shown that, although not without a few difficulties to overcome, it is both practical and possible to meet the global demand for energy from these sources.³⁷⁴

One recent study published in Scientific American in late 2009 outlined a plan to achieve just this – the complete decarbonisation of the global energy system – by the year 2030.³⁷⁵ Based only on existing technology that can already be applied on a large

scale, it called for the building of 3.8 million large wind turbines, 90,000 solar plants and a combination of geothermal, tidal and rooftop solar-PV installations globally. The authors point out that while this is undeniably a bold scheme, the world already produces 73 million cars and light trucks every year. And, for comparison, starting in 1956 the US Interstate Highway System managed to build 47,000 miles of highway in just over three decades, ‘changing commerce and society’.

But, even plentiful supplies of renewable energy are not a ‘get out of jail free’ card for economic growth. The reasons are few and straightforward. First, growth has a natural resource footprint that goes far beyond energy and we have to learn to live within the waste-absorbing and regenerative capacity of the whole biosphere. Secondly, even under the most ambitious programme of substituting new renewable energy for old fossil fuel systems, it will take time and, in climate terms, we are, according to at least James Hansen, already beyond safe limits of greenhouse gas concentrations.³⁷⁶

More global growth will take us even further beyond, with few guarantees that in the space of a few short years the chances of avoiding runaway climate change become unacceptably small. Thirdly, we also have to take into account the fact that, at least until renewable energy achieves a scale whereby its own generated energy becomes self-reproducing in terms of the energy needed for manufacture, even renewable energy systems have a resource footprint to account for. For example, recent research by the Tyndall Centre for Climate Change Research suggests that embodied energy in new energy infrastructure means that it would be approximately eight years before a decarbonisation plan would have a meaningful impact on emissions.³⁷⁷

Renewable technologies are rightly regarded as a potential source of future employment and have a large economic contribution to make, and tend to be seen as carbon neutral or potentially negative.³⁷⁸ Despite this, their overall environmental impact is not entirely benign, and this is particularly evident when renewable technologies are considered on a large-scale, something that is regularly assumed in future emission/economic growth scenarios.

Renewable energy supply is still constrained by the laws of thermodynamics, since energy is being removed from a system; the natural system of the Earth. Whilst this refers to the theoretical limits of energy from renewable sources, there are also practical limits; for example, ‘...large enough interventions in [these] natural energy flows and stocks can have immediate and adverse effects on environmental services essential to human well-being’.³⁷⁹ This is most obviously the case where biomass (e.g. biofuels) are concerned. It has been suggested that given that 30–40 per cent of the

terrestrial primary productivity is already appropriated by humans; any major increase could cause the collapse of critical ecosystems.³⁸⁰

In the IEAAP scenario, it is assumed that biofuels, such as biodiesel and bioethanol will replace mineral oil for use in transport. Without encouraging more land-use change, a major anthropogenic contributor to CO₂ emissions, relying on energy biomass to provide a natural replacement to gasoline (petrol) would mean competition of agricultural land for food and fuel. Yet, with increasing population and increasing energy requirements is this physically possible without causing widespread ecosystem collapse? This is one of the key reasons why Jacobsen and Delucchi, authors of the study published in *Scientific American*, do not rely on biofuels in their plan.³⁸¹

Not all biofuels, though, are reliant on a primary resource feedstock, such as sugarcane and corn (bioethanol) or rapeseed and soya (biodiesel). Cellulosic ethanol can potentially be produced from agricultural plant wastes, such as corn stover, cereal straws, sugarcane bagasse, paper, etc. The technology, however, requires aggressive research and development as it is not yet commercially viable.

At present the energy intensity of this type of ethanol production means that the overall energy value of the product is negative, or only marginally positive, although it is hoped that this will improve as technology develops.³⁸² However, a number of experts feel less positive.³⁸³ For example: according to Eric Holt-Giménez, the executive director of FoodFirst/Institute for Food and Development Policy: 'The fact is that with cellulosic ethanol, we don't have the technology yet. We need major breakthroughs in plant physiology. We might have to wait for cellulose for a long time.'³⁸⁴

Elsewhere, approximately one-half of the global available hydro power has already been harnessed. Little efficiency improvement, also, can be expected from wind turbines, which are at about 80 per cent of the maximum theoretical efficiency.³⁸⁵ The efficiency of solar PV cells could, however, increase from the present 15 per cent to between 20 per cent and 28 per cent in unconcentrated sunlight.³⁸⁶

To be unequivocal, renewable energy is a very good thing and has enormous potential to expand. Something like the Jacobson and Delucchi plan for 2030 is an urgent necessity at a global level if we are to avoid catastrophic global warming.³⁸⁷ As we have shown, zero-carbon or low carbon energy sources are not infinite. Therefore there is no excuse to avoid addressing the waste of energy.

Practical limits to energy efficiency (demand and supply side)

In general, energy efficiency improves at a slow rate of around 1 per cent per year. This rate is not policy-induced and is entirely due to technological developments the Autonomous Energy Efficiency Improvement parameter (AEEI). This global figure, however, has a regional signature. For example, evidence in 1990 suggested that the pace of AEEI in the USA slowed or stopped.³⁸⁸

Overall an energy efficiency improvement rate of 2 per cent (AEEI plus policy intervention per year) is often considered achievable. Higher energy-efficiency improvement rates in the range of 3–3.5 per cent are also thought to be possible due to continuous innovation in the field of energy efficiency.³⁸⁹ For industrialised countries, this means a reduction of primary energy use by 50 per cent in 50 years compared to current levels. This means that in spite of the doubling of energy use under business-as-usual conditions, the energy use could be as low as 50 per cent of the current level.³⁹⁰

But given the limitations discussed above, significant improvements to efficiency increases are only likely to be due to improvements in chemical processes rather than fuel combustion and increases in end-user energy efficiency.³⁹¹

In terms of end-user efficiency, there is a long way to go. ‘Unrealised’ energy conservation measures in OECD countries may amount to 30 per cent of total energy consumption.^{392,393} Some suggest that if there are no economic, social or political barriers, an instantaneous replacement of current energy systems by the best available technology would result in an overall efficiency improvement of 60 per cent.³⁹⁴ This is contrary to the forecast improvement of efficiency by 270 per cent if historical efficiency improvement rate of 1 per cent continues and is maintained over the next 100 years. And, even if this was possible, the improvement rate of 1 per cent would be unlikely to continue beyond 100 years.³⁹⁵

Demand side barriers

*When energy efficiency promoters claim that we can get more out of less, we must conclude that the focus so far has been to get more out, period!*³⁹⁶

Nakicenovic and Gruebler (1993)

Throughout this report, we have shown that observations of changes to carbon intensity and energy intensity of the economy over the past decade have failed to improve at a

rate necessary to slow the increase in greenhouse gas concentrations, and in recent years appear to be heading in the opposite direction. This is supported by a recent report by the IEA on trends in energy consumption between 1973 and 2004.³⁹⁷ The report found that while energy intensity had fallen by over 30 per cent since 1973 – it now takes one third less energy to produce a unit of GDP in IEA economies – the rate of change has slowed.³⁹⁸ Improvements in energy intensity have slowed in all sectors of the economy since the 1980s. As such, projecting forward historical rates of energy efficiency are misleading. But this is the basic assumption made by most the future emissions scenarios.

While we have shown that improvements to supply-side efficiency is limited by practical limits to energy conversion and technological, what are the drivers of demand side energy efficiency? Earlier in the report we discussed the significance of the rebound effect, whereby efficiency savings are offset by increases in consumption (see Box 8). There are a number of additional barriers to demand side efficiency – ϵ_{ea} (see Equation 1). These are shown in Box 25.

All these factors contribute to the failure of energy efficiency to drive absolute emissions downward. The main reason, however, relates to the market imperfection. For example the IEA found that the price signals in the 1970s did more to increase efficiency than improved technology has done since the 1980s.³⁹⁹ In other words, the cost of energy is currently too low. Because of subsidies or the externalisation of the environmental cost, the wasteful use of energy is encouraged.

Limits to the speed of technological uptake

*The magnitude of implied infrastructure transition suggest the need for massive investments in innovation energy research.*⁴⁰⁰

Hoffert *et al.* (1998)

Based on historical evidence, what is the capacity for social and institutional organisations to rapidly change? Is there a limit to our ability to produce knowledge and new technology to deal with a problem? Surprisingly, this is a vastly under researched field. For example, Tim Lenton and colleagues conclude in their paper on tipping points with the following statement: 'A rigorous study of potential tipping elements in human socioeconomic systems would also be welcome, especially to address whether and how a rapid societal transition toward sustainability could be triggered, given that some models suggest there exists a tipping point for the transition to a low-carbon-energy system.'⁴⁰¹

Box 25. Barriers for energy efficiency improvements^{402, 403}

Technical barriers: Options may not yet be available, or actors may consider options not sufficiently proven to adopt them.

Knowledge/information barriers: Actors may not be informed about possibilities for energy-efficiency improvement. Or they know certain technologies, but they are not aware to what extent the technology might be applicable to them.

Economic barriers: The standard economic barrier is that a certain technology does not satisfy the profitability criteria set by firms. Another barrier can be the lack of capital for investment. Also the fact that the old equipment is not yet depreciated can be considered as an economic barrier.

Institutional barriers: Especially in energy-extensive companies there is no well-defined structure to decide upon and carry out energy-efficiency investments.

The investor-user or landlord-tenant barrier: This barrier is a representative of a group of barriers that relate to the fact that the one carrying out an investment in energy efficiency improvement (e.g., the owner of an office building) may not be the one who has the financial benefits (in this example the user of the office building who pays the energy bill).

Lack of interest in energy-efficiency improvement: May be considered as an umbrella barrier. For the vast majority of actors, the costs of energy are so small compared to their total (production or consumption) costs that energy-efficiency improvement is even not taken into consideration. Furthermore, there is a tendency that companies, organisations and households focus on their core activities only.

While there is a growing awareness of the urgency with which the transition to a low carbon economy must be made, identification of potential tipping elements in human systems is still a largely under-researched area.

A recent report to the US Department of Energy has noted that it takes decades to remake energy infrastructures.⁴⁰⁴ This is further supported by Figure 20 which maps capital stock turnover rates for energy related infrastructure. Decisions made now in terms of transport and energy infrastructure and the built environment will determine the capability of a nation to reduce its carbon footprint. Highly centralised energy systems, inefficient buildings and poor planning will make a difficult task even more challenging.

Climate change has long been viewed as a pollution problem. This has led to the interpretation of climate change in predominantly scientific terms by policy makers, the media and environmental NGOs resulting in technocentric responses gaining more interest than any more systemic change. However, the growing emphasis on the technological or market-based initiatives as a cure-all ignores what we have shown in this report – that the challenges we currently face, have their roots in a faulty economic system. So, with the vast majority of efficiencies realised, it appears restructuring of the economic system may be the only route by which we can achieve the emission cuts necessary.

In the context of energy systems, the findings of this report only add to the desirability of carefully considered low carbon planning, and other prompt actions to slow down the use of energy and resources. Such solutions can also improve inter alia resilience to exogenous shocks such as volatile food or energy prices, local economic regeneration, social cohesion, physical and mental well-being, employment opportunities and the increased individual and community capacity to reduce emissions and resource use. For example, investment into renewable energy can create new jobs often in areas where they are needed the most. If installed at the local level, renewable energy schemes can also contribute to local economic regeneration, social cohesion (an important factor for adaptive capacity) and improve environmental literacy. Energy efficiency and decentralised or low carbon energy production targeted at low-income households also has the potential to reduce fuel poverty or access to energy caused by poor living standards and low-incomes.

Equity considerations

So far, in the growth and emissions scenarios, we have abstracted from national differences to look solely at globally aggregate data. Unfortunately, detailed national projections for fuel mix and fuel usage are not readily available, not to mention the difficulty of making assumptions about national technology levels and adoption speeds. It is possible, however, to look at national level GDP and growth data, as this is more easily available. Additionally we have been abstracting from actual predictions of growth to look at the energy and emissions possibilities given varying levels of growth.

The scenarios presented earlier indicate that even with very optimistic assumptions about energy and carbon intensity improvements and technology adoption, the world will not meet the target for emissions reductions. To meet that target will require aggressive technological improvements combined with a slowing of our use of resources and a reduced demand for energy-intensive goods and services. That implies lower growth. Yet the world is not an equal place, with income and emissions levels varying by orders of magnitude from one country to the next. Expecting reductions in growth along with carbon/energy intensity improvements may seem reasonable for industrialised economies, where additional income does little to increase well-being in society.

Clearly the situation is different in low-income countries, some of which have incredibly low income levels along with their high mortality rates, low life expectancy and low measures of well-being. These countries could not be expected to bear equal measures of growth reduction, especially since they were not responsible for the historical emissions which have brought us to this critical threshold of rapid climate change.

Allowing some low-income countries to grow rapidly and offsetting that with further reductions of growth in the industrialised world would not be very costly for most cases, as the low-income countries start with low bases of economic size. Ten per cent growth in Malawi, for example, would require little offsetting growth reductions in the UK. But this is not uniformly the case. Leaving aside the problems of domestic inequality, fast-growing economies such as India and China have large bases of economic activity, despite their comparatively lower per capita incomes. Faster growth in those two economies, which could help eliminate global poverty if well distributed, would need to be accompanied by off-setting reductions in the industrialised world.⁴⁰⁵ Consumption in the North simply cannot continue at its current level if society is to address both the poverty and climate change problems.

If not the economics of global growth, then what? Getting an economy the right size for the planet

The stationary state

The lineage of the notion of 'one planet living' can be traced at least as far back as the early nineteenth century. Philosopher and political economist John Stuart Mill was shaped by the human and environmental havoc of the voracious Industrial Revolution.

In reaction to it, he argued that, once certain conditions had been met, the economy should aspire to exist in a 'stationary state'. It was a hugely radical notion for the time. Mill thought that an intelligent application of technology, family planning, equal rights, and a dynamic combination of a progressive workers movement with the growth of consumer cooperatives could tame the worst excesses of capitalism and liberate society from the motivation of conspicuous consumption.

He prefigured Kropotkin's analysis that economics could learn from the success of cooperation, or 'mutual aid' as he coined it, in ecological systems, itself a riposte to the fashionable misappropriation of Darwinism to social and economic problems.⁴⁰⁶ The latter economic folk wisdom remains nevertheless strong. And even today, the Anglo Saxon economic model is commonly defended with similar misappropriations of Darwin that emphasise the 'law of the jungle' and 'survival of the fittest.' This view suggests that competition in economics, as in nature, should be the natural, dominant mode of operation. Yet, actual evolutionary biology has moved far beyond this caricature, identifying a wide range of different and equally successful strategies in evolution alongside competition.⁴⁰⁷

These include **symbiosis** (an example of which is the bacteria which fix nitrogen in plant roots consequently making life possible), **collaboration** (as was the case with primeval slime mould), **co-evolution** (the pollinating honey bee responsible for

about one in three mouthfuls of the food we eat), and even **reason** (as with problem solving animals – like elephants, dogs, cats, rats, sperm whales and, sometimes, humans). Optimal **diversity** too is considered a key condition – nature’s insurance policy against disaster – suggesting that economic systems which allow clone towns to be dominated by massive global chain stores, are probably a bad idea.

Mill also prefigured Keynes’s hope, and similar faith in technology, that once the ‘economic problem’ was solved, we would all be able to turn to more satisfying pursuits, and put our feet up more. He also prepared the ground for the emergence of ecological economics.

The Steady state

In a fairly direct line of intellectual descent, economist Herman Daly has done perhaps more than anyone to popularise the notion of what he calls ‘steady state’ economics. His comprehensive critique, worked-up over decades, decries the absence of any notion of optimal scale in macro-economics, and the persistent, more general refusal of the economics profession to accept that it, too, like the rest of life on the planet, is bound by the laws of physics (see Introduction).

As he wrote in *Beyond Growth*: ‘Since the earth itself is developing without growing, it follows that a subsystem of the earth (the economy) must eventually conform to the same behavioural mode of development without growth.’⁴⁰⁸

Of course the big question concerns when, precisely, the ‘eventually’ moment comes. Daly borrows a public safety analogy from the shipping industry to demonstrate what is needed ecologically at the planetary level.

The introduction of the ‘Plimsoll line’ was, so to speak, a watershed to do with a watermark. When a boat is too full, rather obviously it is more likely to sink. The problem used to be that, without any clear warning that a safe maximum carrying capacity had been reached, there was always an economic incentive to err on the incautious side by overfilling. The Plimsoll line solved the problem with elegant simplicity: a mark painted on the outside of the hull that indicates a maximum load once level with the water.

Daly’s challenge to economics is to adopt or design an equivalent, ‘To keep the weight, the absolute scale, of the economy from sinking our biospheric ark’.⁴⁰⁹ But Daly is not a crude environmental determinist; for any model to work he insists that alongside

optimal scale, equally important is a mechanism for optimal distribution based on equity and sufficiency.

To date, the nearest, in fact, only, leading contender to provide the environmental Plimsoll line is the Ecological Footprint. Before the Contraction and Convergence model, which is designed to manage safely greenhouse gas emissions, was ever thought of, Daly identified its basic mechanism as the way to manage the global environmental commons. First, he said, you need to identify the limit of whichever aspect of our natural resources and biocapacity concerns you, then within that, allocate equitable entitlements and, in order to allow flexibility, make them tradable. Such an approach could be applied to the management of the world's forests and oceans as much as CO₂. Daly credits the innovative American architect and polymath Richard Buckminster Fuller for first suggesting the approach. At a fundamental level, this is the primary mechanism to avoid the tragedy of the commons.

In addition, an indicator such as the *Happy Planet Index*⁴¹⁰ which incorporates the Ecological Footprint helps to reveal the degree of efficiency with which precious natural resources are converted into the meaningful human outcomes of long and happy lives.

At the 'eventually' moment, or rather well before, these other ways of organising and measuring the economy become vital. In one sense it has already passed. According to the Ecological Footprint, the world has been over-burdening its biocapacity – consuming too many natural resources and producing more waste than can be safely absorbed – since the mid-1980s. We've been living beyond our ecological means. But, at what point does the damage become irreversible? This will be different for different ecosystems. But, where climate change is concerned, we have drawn a line in the atmospheric sand at the end of 2016. Based on current trends and several conservative assumptions, at that point, greenhouse gas concentrations will begin to push a new, more perilous phase of global warming.⁴¹¹

Dynamic equilibrium

'Stationary', 'steady', up to a point these words communicate the message that, logically, a subset of a system (the economy) cannot outgrow the system itself (the planet), and the need to establish a balance. Why suggest yet another term for an essential characteristic of true sustainability?

Yet, the terms 'stationary', and 'steady', are unattractive for our purposes. They fail to capture sufficiently the dynamism of the interactions between human society, the economy and the biosphere. They wrongly appear to suggest for economics, what was once famously, and with epic error announced for history, namely its end.

But, on the contrary, writes Daly, it is just that a very different economics is needed, one that is; 'a subtle and complex economics of maintenance, qualitative improvements, sharing frugality, and adaptation to natural limits, It is an economics of better, not bigger'.⁴¹²

'Dynamic equilibrium', is both a more accurate description of the condition we have to find and manage, and a more attractive term. Found typically in discussions of population biology and forest ecology, it captures a mirror of nature for society, in which, within ecosystem limits, there is constant change, shifting balances and, evolution. 'Dynamic' in the sense that little is steady or stationary, but 'equilibrium' in that the vibrant, chaotic kerfuffle of life, economics and society must organise its affairs within the parent-company boundaries of available biocapacity.

In his parting address from the World Bank, where he worked for six years, Daly left his colleagues with a formula for sustainability: stop counting the consumption of natural capital as income; tax labour and income less, and resource extraction more; maximize the productivity of natural capital in the short run and invest in increasing its supply in the long run; and most contentiously, abandon the ideology of global economic integration through free trade, free capital mobility, and export-led growth.

nefs report, *The Great Transition*, explores how best to organise an economy that exists in a state of dynamic equilibrium with the biosphere. That and other research underway seeks to address all the usual questions such as ensuring livelihoods, security in youth and old age, maximising well-being and social justice. The point of this report has been simply to establish the case, as far as possible beyond question, that such an economy is needed.

The challenge: How to create good lives and flourishing societies that do not rely on infinite orthodox growth

This report set out to examine the physical and environmental constraints to unlimited global economic growth as measured by GDP. Taking climate change and fossil fuel use as a particular focus, we find that these constraints at the global level are real and immediate. This means, that in order to allow economic growth

in low per capita income countries where, for example, rising income has a strong relationship to greater life expectancy, there will need to be less growth in those high-income countries where the relationship to increasing life expectancy and satisfaction has already broken down.

It is not the purpose of this report to explore in detail what the latter might look like in practice. This is the focus of a large amount of work by **nef** that is unnecessary for us to duplicate. We refer the reader, for example, to the book produced by **nef** and the Open University, titled *Do Good Lives Have to Cost the Earth?*, and to recent **nef** reports including:

- ***The Happy Planet 2.0*** (2009), which provides a new compass to set society on the path to real progress by measuring what matters to people – living a long and happy life – and what matters to the planet – our rate of resource consumption.
- The ***National Accounts of Well-Being*** (2009), proposes nations should directly measure people's well-being in a regular and thorough way, and that policy is shaped to ensure high, equitable and sustainable well-being.
- ***The Great Transition*** (2009), which is a bold and broad plan for the UK that demonstrates how, even with declining GDP, it is possible to see rises in both social and environmental value. The plan envisages a pathway of rapid decarbonisation for the economy and significant increases in equality in society.

It is possible, though, to say something briefly here about why the things that lock economies like the UK into GDP growth are not immutable. In Box 1 at the beginning of the report we summarised those reasons as being mainly threefold.

First, governments plan their expenditure assuming that the economy will keep growing. If it then didn't, there would be shortfalls in government income with repercussions for public spending. Secondly, listed companies are legally obliged to maximise returns to shareholders, and investors generally take their money wherever the highest rates of return and growth are found. Thirdly, nearly all money is lent into existence bearing interest. For every pound lent, more must be repaid, demanding growth.

Encouragingly, however, none of these three conditions is a given, unchangeable 'state of nature'. Economic rules and habits are not like the laws of physics. Today's

fiduciary duties on company management are not on a par with the force of gravity. These things are the result of cultural and political choices, which can, if necessary, be changed in the light of necessary and urgent circumstances.

In terms of government spending on essential services, governments have more room for manoeuvre than they like to admit. When the financial crisis hit, in the UK alone over £1 trillion was found to support the banks, apparently from nowhere. It can be done. Through so-called 'quantitative easing' money really was conjured from thin air (the dirty little secret of banking is that this is practically what happens all the time when people borrow, for example, to buy a house).

Governments can also change priorities, spending less on unproductive military expenditure and more on schools, hospitals and support for those who need care. New techniques employing greater reciprocity with the users of public services can also radically reduce the upfront cash-cost of services by making them more effective (through so-called 'co-production'). There's also no reason why fairer taxation and greater redistribution, coupled with better services cannot provide security for all in old age, removing the insecurity that makes us all worry about having a private pension with a high interest rate.

Herman Daly makes the point that in a non-growing, steady state (or dynamic equilibrium) economy it might actually be easier to approach full employment. With lower levels of material throughput and lower levels of fossil fuel energy use, the proportion of human energy input (labour) is likely to increase. Generations of having people made redundant by machines largely powered by coal, oil and gas could be reversed. He writes: "There are several reasons for believing that full employment will be easier to attain in a SSE [steady state economy] than in our failing growth economies... the policy of limiting the matter-energy throughput would raise the price of energy and resources relative to the price of labour. This would lead to the substitution of labor for energy in production processes and consumption patterns, thus reversing the historical trend of replacing labour with machines and inanimate energy, whose relative prices have been declining."¹⁴¹³

Such a new economy implies the need for a great 'reskilling', for example in the food economy, and the growth of urban agriculture. Other adaptations could bring a range of social, environmental, and economic benefits. A redistribution of paid employment via a shorter working week, tackling the twin problems of overwork and unemployment, would free up time for people to do more things for themselves, each other and the community, and reduce their dependence on paid-for services.

Growth isn't possible

At the corporate level, there are many other forms of governance that could reduce or remove the pressure to service shareholders who have a one-eyed obsession with maximum growth and returns. Cooperatives, mutuals, publicly owned companies and social enterprises all have broader or simply different objectives.

Finally, when it comes to monetary systems, there is a whole world of alternatives, and a long history of innovation, some of it explored in the *Green New Deal*, published by **nef** in 2008, and widely written about in the works of people like Bernard Lietaer, David Boyle, Ann Pettifor and James Robertson.⁴¹⁴ There are different forms of exchange, such as Time Banks,⁴¹⁵ and different kinds of local and regional currencies, each with their own characteristics. Not all money need be interest bearing. Low- or no-cost credit can be created by Central Banks for the purpose of achieving particular tasks – such as building new infrastructures for energy, transport, farming and buildings – for the environmental transformation of the economy. Such money can have special conditions attached to prevent it becoming inflationary.

Unending global economic growth, it would seem therefore is not possible, but also neither desirable nor necessary. If you have any doubts, ask a hamster.

Endnotes

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