The Actuarial Profession
making financial sense of the future

Research Report
Resource constraints: sharing a finite world

Implications of Limits to Growth for the Actuarial Profession

The evidence and scenarios for the future

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Resource constraints

The Evidence and Scenarios for the Future

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Written by
Dr Aled Jones, Irma Allen, Nick Silver,
Catherine Cameron, Candice Howarth & Ben Caldecott

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1. Introduction

In 1972 *Limits to Growth*[1] was published by the Club of Rome. This report examined the resource and political constraints that existed at the time and made predictions for the constraints this would put on global growth over the upcoming decades.

Limits to Growth – the 30 year update[2] was published in 2004 remodelling the resource constraints and making further predictions including the latest available information. Over 30 years after the original publication a report by CSIRO[3] examined the predictions made by *Limits to Growth* and showed that there was good agreement with observed data.

The Institute and Faculty of Actuaries wish to examine the implications of the findings of limits to growth on financial markets and consequential impacts on actuarial advice. This report, led by the Global Sustainability Institute (GSI) at Anglia Ruskin University, highlights the evidence behind resource constraints and explores these implications as a first step in this endeavour.

1.1 Finance and resources

Human society operates with a fairly simple model of capital flows based on providing the goods and services that people use. The current economic system behaves as if it is a linear system with no concept of limitations to resources. Some economists and market analysts would argue that the price of a resource increases the more scarce it gets, or the more damage it does if that damage is measured and priced, and therefore the market will create solutions to resource scarcity. However, there is increasing evidence that the current system, with its inputs, outputs and market imperfections (in particular the lag in time between pricing and impact, incomplete resource data and unaligned policy frameworks) means that an appropriate management of scarce resources is not happening.

Several models have been developed to try and understand the limits to sources of capital (natural, human, social etc) and what this potentially means for society. These include the *Planetary Boundaries*[4] work of the Stockholm Resilience Centre and the *One Planet Living* work of WWF.

However, none of these models explores the financial implications of such limits and how these potentially impact decision making processes and risk models within the finance sector. If natural resource limits do result in changes to the economic system this could have a significant impact on the valuation of fossil fuel assets or companies reliant on limited resources. For example, a recent study[5] has shown that the valuations of US utilities could be overstated, and their cost of debt, as measured in bond ratings, could be incorrect given their dependence on water which is increasingly scarce in their immediate geographical areas.

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[1] Meadows, Meadows, Randers & Behrens, (1972), *Limits to Growth*, Club of Rome

[2] Meadows, Randers & Meadows (2004), *Limits to Growth – the 30 year update*, Earthscan

[3] Turner (2008), *A comparison of the limits to growth with thirty years of reality*, Socio-Economics and the Environment in Discussion

[4] Rockstrom et al (2009), *A safe operating space for humanity*, Nature 461, 472-475 (see also: http://www.nature.com/news/specials/planetaryboundaries/index.html)

[5] Leurig, & PricewaterhouseCoopers LLP (2010). *The Ripple Effect: Water risk in the municipal bond market*. Boston: CERES

1.2 Growth and limits

The question of the long term sustainability of economic growth has received significantly more attention globally over the last few years. As the traditionally developed economies find it difficult to sustain economic growth understanding new risks to fragile recoveries is becoming more important. Traditional growth has been very visible through the consumption of resources – after being invented in 1947 it is estimated that in 2010 there were more than 1 billion transistors per person globally[6]. However, the resources required to sustain the current level of consumption (as measured through Gross Domestic Product) may not be available over the next few decades.

If resource constraints do end up providing a limit to economic growth this will have a significant impact on a country's finances and a systemic risk may exist.

1.3 Report structure

This report attempts to bring together the latest information and discourse on limits to growth and resource constraints.

We first outline the narratives around economics and limits to growth. Chapter 2 explores some of the limitations of the way we measure growth. Chapter 3 explores the three main narratives around the limits to growth including 'growth is the solution', 'green growth' and 'the end of growth'. We also summarise an increasingly present narrative around the implications of going 'beyond the limits'.

We then outline the evidence for potential resource constraints. Chapter 4 highlights the current resource constraints across a number of key sectors including oil, coal, natural gas, uranium, land, water, metals and food. We also explore limits in other key 'resources' including population and the availability of capital. Chapter 5 presents two cases studies, water and oil, to allow a more detailed look at two examples and unpack the various connections a little further.

The potential impact of resource constraints on the global economy and society is then highlighted. In chapter 6 we present our scenarios model for the future which will be used to explore the implications of resource constraints.

We end with a case study of how this global impact may affect a particular actuarial practice. Chapter 7 explores some of the implications on pension and investment returns. Finally in chapter 8 we draw together some conclusions and make some tentative recommendations around possible next steps for the actuarial profession.

[6] Fransilla (2010), *Introduction to Microfabrication,* Wiley

2. The economics of Limits to Growth

What is meant by economic growth and is it necessary?

`You can have "growth" – for now – or you can have "sustainable" forever, but not both. This is a message brought to you by the laws of compound interest and the laws of nature[7].'

2.1 Introduction

In order to answer the question `what is growth and why is it necessary' this chapter first discusses the definition, origins and measurement of growth, highlights its shortcomings and examines the range of alternative approaches that have been put forward and/or are increasing in practice.

2.1.1 Growth definitions, measurement and evolution

Economic growth is simply the increase in the amount of the goods and services produced by an economy over time. It is conventionally measured as the percentage rate of increase in *real gross domestic product, or real GDP*. Classical growth theory at the macro level assumes that output (Y) = consumption(C) + investment (I) + government (G) + (exports (X)- imports (M)). The relationship can be written as follows[8]:

$$Y=C+I+G+(X-M)$$

Growth in output results from increases in production factors (physical capital and labour) and productivity, which rises as a result of technological change, including changes in organisation and practices. The environment does not play an explicit productive role in this approach. Nor is there a mainstream economic theory which treats resources as if they are finite, although more recently ecological economists have sought to correct this (e.g. Herman Daly, Paul Hawken[9]).

Economic growth can be measured by the increase in the amount of goods and services produced by an economy over time. This is the percentage increase in real Gross Domestic or National Product. (i.e. adjusted for inflation).

Gross Domestic product (GDP) refers to the market value of all officially recognised final goods and services produced *within* a country in a given period.

Gross National Product (GNP) is the market value of all products and services produced in one year by labour and property supplied by the *residents* of a country.

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7 Jeremy Grantham, *`Your Grandchildren have no value (and other deficiencies of capitalism)',* February 2012 GMO Quarterly newsletter

8 Classical growth theory at the level of the firm assumes that output (Y) is produced using technology (A), physical capital (K), and labor (L). The relationship can be written as follows:

$$Y = f(A, K, L).$$

9 It can be argued that natural capital is implicitly included within physical capital. The assumption is made that natural capital and physical capital are fully substitutable. The history of Nauru highlights the absurdity of this assumption. http://en.wikipedia.org/wiki/Nauru

Unlike GDP, which defines production based on the geographical *location* of production, GNP allocates production based on *ownership*.

The measure was developed by Simon Kuznets in the 1930s when the US was trying to address the Great Depression. The rising role of government in the economy led to an increased need for a comprehensive set of data for national economic activity. The use of GDP spread globally after the Bretton Woods Conference in 1944, when the IMF and World Bank were created. These institutions adopted the use of the GDP measure from the USA and UK to guide their policy advice and investment choices. The adoption of the GDP measure is credited with reducing the severity of business cycles and the era of strong economic growth after the World War II.

There are numerous economic growth theories including the role of increasing productivity, the enabling role of technology, the role of energy conversion, the role of cognitive wealth, the unified growth theory, the Big Push, the role of the climate in the development of institutions and human capital and growth.

Recent critiques of economic growth have looked at the resource depletion arguments (explored in more detail in section 4 of this report), the negative environmental impacts of growth, also the impacts of greenhouse gas (GHG) emissions on the planet and the need for more equitable growth, as well as empirical observations that after certain thresholds in developed countries, continuing growth in income and consumption do not lead to higher reported levels of well-being.

As The Limits to Growth: The 30 Year Update put it `*public discussions of economic matters are full of confusion, much of which comes from a failure to distinguish between money and the real things money stands for. Our emphasis is placed on the physical economy, the real things to which the earths limits apply, not the money economy, which is a social invention not constrained by the physical laws of the planet.*'

2.1.2 Some early warnings about the shortcomings of the GNP measure

The recognition of the shortcomings a focus on the growth of GNP have been well understood since the early study of political economy. A short chronological sample of more recent critiques is provided below:

John Stuart Mill in 1848[10] looked upon political economy *'not as a thing in itself, but as a fragment of a greater whole; a branch of social philosophy, so interlinked with all the other branches that its conclusions (…) are only true subject to interference & counter-action from causes not directly within its scope.'* Mill expresses concern that the then cornerstones of British economic growth—the division of labor (including the increasing simplicity and repetitiveness of the work) and the growing size of factories and businesses—led to a spiritual and moral deadening.

Simon Kuznets, one of the principal architects of what became the standard way of creating national accounting systems, declared in 1933 that *"the welfare of a nation can scarcely be inferred from a measurement of the national income"* and went on to warn in 1962 "*Distinctions must be kept in mind between quantity and quality of growth, between its costs and return, and between the short and the long term. Goals for more growth should specify more growth of what and for what."*

[10] J.S. Mill *Principles of Political Economy, 1848*

After World War II EF Schumacher highlighted that growth had *`subtly moved from being a means to an end, to an end in itself.'* Schumacher also introduced the importance of appropriate scale into economics, as well as being one of the first to distinguish between exhaustible and renewable resources. In particular, he noted that an economy cannot continue indefinitely by converting its stocks to income. He also questioned the whole purpose of the economy highlighting that 'good work' and community were important elements of well-being and were being undermined by the pursuit of growth as an end in itself.

Almost from the moment that a system of national accounts was introduced in the UK, one of its key architects, J.M Keynes warned not to '*overestimate the importance of the economic problem, or sacrifice to its supposed necessities other matters of greater and more permanent significance. '* He also understood and recognised that economic growth was originally a means to an end. *`The day is not far off when the economic problem will take the back seat where it belongs, and the arena of the heart and the head will be occupied or reoccupied, by our real problems – the problems of life and of human relations, of creation and behaviour and religion.'*

In 1972 the Club of Rome produced a report the Limits to Growth[11]. This used systems dynamics theory and computer modeling to analyze the long term causes and consequences of growth in the world's population and material economy. It asked questions such as *`Are current policies leading to a sustainable future or collapse? What can be done to create a human economy that provides sufficiently for all?'* It thus had a similar theme and purpose to the work of this report.

Twelve scenarios from the World 3 computer model showed different possible patterns of world development over the two centuries from 1900 to 2100. These illustrated how world population and resource use interact with a variety of limits. In reality limits to growth (LTG) take many forms, but the LTG analysis focused principally on the planet's physical limits in the form of depletable natural resources and the finite capacity of the Earth to absorb emissions from industry and agriculture. In every realistic scenario the model found that these limits force an end to growth sometime in the 21st century. This can take many forms for a variety of causes. It could be collapse[12] or it could also be a smooth adaptation of the human footprint to the carrying capacity of the Earth. By specifying major changes in policies the model can generate scenarios with an orderly end to growth followed by a long period of relatively high human welfare. The report attracted significant controversy and rejection of its scenarios, however the data available to the present day agrees worryingly well with the projections, as the graphs below illustrate.

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[11] Donella Meadows, Jorgen Randers, Dennis Meadows & William W Behrens *The Limits to Growth, 1972*.

[12] 'Collapse' is a loaded term (and not always understandable in economic terms). In this report we try to differentiate between instances of long term economic decline (which could be a result of negative growth rates over an extended period or short economic 'shocks' followed by periods of stagnation) and 'collapse' - times when constraints placed on a nation, or the globe, are so severe that international trade and political stability are removed or a particular ecosystem goes beyond a tipping point leading to a 'collapse' – the point after which that service is no longer available.

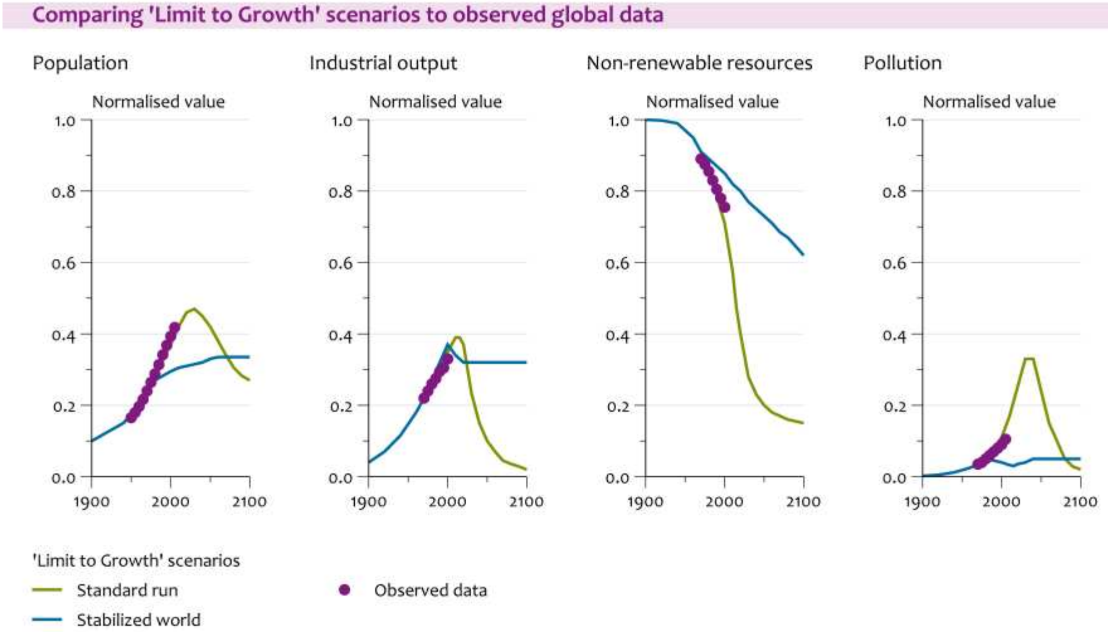

Figure 1: Comparison of World3 Limits to Growth scenarios to observed data. [13]

Without needing to understand the modeling involved the basic conclusions stem from `*an understanding of the dynamic patterns of behaviour that are obvious, persistent and common features of the global systems: erodable limits, incessant pursuit of growth and delays in society's responses to approaching limits.'*

Max Neef made the distinction between needs and satisfiers. Needs are satiable, whereas satisfiers are insatiable[14]. Human needs are seen as few, finite and classifiable (as distinct from the conventional macro economic theory which assumes that wants are infinite and insatiable). Materials goods and services have become pseudo satisfiers for other needs such as status; relationships; security. This is picked up by Tim Jackson in `Prosperity without Growth', and others who have argued that our social relations are now mediated through products.

[13] *Growing within Limits: A Report to the Global Assembly 2009 of the Club of Rome,* PBL Netherlands Environmental Assessment Agency, October 2009

[14] Manfred Max-Neef, *Human Scale Development: an Option for the Future*, 1987

Figure 2: Max-Neef fundamental human needs.

So the risks of a heavy reliance on a simple measure of growth in GNP have been highlighted and understood since the measure was first adopted. However the reliance on GNP growth as a measure of economic success has also encouraged another view, established many decades ago and still a strong theme in the prevailing orthodoxy. Arthur Burns, when Chairman of President Eisenhower's Council of Economic Advisers in 1953-4 is quoted as saying *`America's ultimate economic purpose is to provide more consumer goods.'* (He was later Chairman of the Federal Reserve from 1970-78).

In 1955 economist and retail analyst Victor Lebow famously commented on the role of consumption in an economy:

`Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfactions, our ego satisfactions, in consumption. The measure of social status, of social acceptance, of prestige, is now to be found in our consumptive patterns. The very meaning and significance of our lives today expressed in consumptive terms. The greater the pressures upon the individual to conform to safe and accepted social standards, the more does he tend to express his aspirations and his individuality in terms of what he wears, drives, eats - his home, his car, his pattern of food serving, his hobbies.

These commodities and services must be offered to the consumer with a special urgency. We require not only "forced draft" consumption, but "expensive" consumption as well. We need things consumed, burned up, worn out, replaced, and discarded at an ever increasing pace. We need to have people eat, drink, dress, ride, live, with ever more complicated and, therefore, constantly more expensive consumption.'[15]

We can see here how marketing shifted from providing information about products to selling an aspirational lifestyle – rooted in the psychology of dissatisfaction. The need to consume in order to grow the economy was famously echoed in 2006 when then President George Bush warned of the challenge ahead in 2007 and said: *`This work begins with keeping our economy growing. … And I encourage you all to go shopping more.'*[16]

[15] Price competition in 1955, Victor Lebow in Journal of Retailing, Spring 1955
[16] www.nytimes.com/2006/12/20/washington/20text-bush.html?pagewanted=all

However, surveys asking people about their life satisfaction in wealthier nations finds that the relationship between growth in GDP per capita and improvement in well being is not as clear cut as has been assumed. In mature economies, where basic needs (water, food, shelter, security) have been met, a high standard of living is enjoyed and GDP has grown, but life satisfaction has not. [17]However emerging economies quite reasonably want to grow their economies to achieve the same standard of living and view the conventional growth path as the means to achieve this, supporting the post WWII view that growth is a good thing.

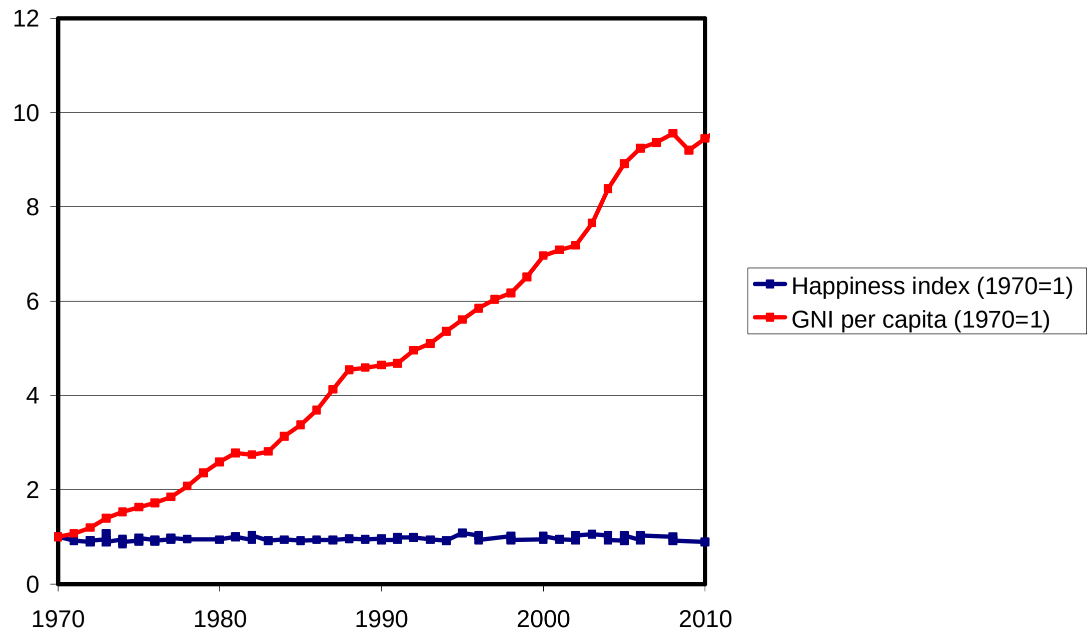

Figure 3: Comparison of Gross National Income (GNI) per capita and life satisfaction over the past few decades. [18]

Edward Abbey[19] suggested that *"growth for the sake of growth is the ideology of the cancer. What is our economy for? It is not an end in itself; it is the means of producing the things we need and want, and allocating them through money and markets. Its purpose is to provide for our material well-being and then get out of the way and let us turn to more important matters."*

2.2 Measurement of Growth

2.2.1 The shortcomings of the GDP measure

GDP has become the standard measure of the size of an economy and has for several decades been the default metric for economic progress and success. Since at least the post

[17] This maybe due to the way the survey is carried out, with life satisfaction marked out of 100, so it is automatically limiting, unlike the GDP measure. Or it may be about relative satsifaction, `keeping up with the Jones', where the sight of more wealth elsewhere leads to stagnant or lower satisfaction.

[18] Happiness index taken from World Database of Happiness, Measurement type: 111B/3-step verbal happiness, http://www1.eur.nl/fsw/happiness/hap_nat/desc_qt.php?qt=1 and Gross National Income (GNI) per capita taken from World Bank using World Bank Atlas method.

[19] Edward Paul Abbey (January 29, 1927 – March 14, 1989), American author and essayist noted for his advocacy of environmental issues. *The Monkey Wrench Gang* (1975) is cited as the inspiration for the formation of the civil society organisation *Earth First*, together with Rachel Carson's *Silent Spring*.

WWII era the presumption has been that as long as GDP is growing the other things that we aspire to (whether health, wealth, happiness etc) will follow through a process of `trickle down.' GDP can be a useful measure in providing information about the state of the economy, as it does now, providing information on employment, government revenue and company profits. This short term immediate information on whether or not an economy is in recession is very different from recognising the long run impacts of growth, year on year, bigger and bigger, as we will examine in 2.2.3.

Immediately after the war there was an urgent need to rebuild nations and economies, therefore the maximisation of production was strongly linked to improving the material welfare of people. However, this focus on increasing production then became the main foundation of the United Nations System of National Accounts, so complementary measures of welfare and societal progress were not pursued. The raft of recent initiatives indicates a growing recognition that the simple GDP measure is not adequate, (or is being misused) hence the rise in measures to supplement this, or in some instances provide an alternative.

Along with this there is the challenge of the rise in intangible services in mature economies, which are not susceptible to the same measurement as in an older primary or secondary based economy (e.g. agriculture, coal, oil and gas or cars, white & electronic goods and widgets). It is much harder to measure tertiary services like health care (which will be a rising proportion of services in mature economies with aging populations) and other intangible services such as entertainment.

The principle flaws to GDP are understood to be that:

i) It is neutral in its measurement of goods and services adding up goods and bads together. This has also been called *`not measuring ilth'* by Herman Daly[20]. e.g. Nuclear waste, congestion, pollution, wells drying up. So it fails to capture the negative consequences of growth, including rising greenhouse gas emissions, whilst defensive and restorative expenditures such as cleaning up the 'bads' – such as oil spills – show as positively contributing to GDP .

A subset of this point that is particularly relevant to actuaries is that this does not take account of risk. So a short term borrowing and spending spree would provide a boost GDP that would be misleading in the longer term, as we experience now.

Or more recently as Paul Hawken put it *`At present, we are stealing the future, selling it in the present, and calling it GDP.'*[21]

ii) Not measuring positive aspects of our lives which are not monetised, such as caring for children, the sick or elderly or housework, working in the community, the natural environment. As a result GDP can mask the breakdown of the social structures and natural habitats; and worse, it can capture this breakdown as economic gain. So the depletion of finite natural capital, whilst treating it as income, is a failing of GDP now gaining more recognition. We return to this in section 2.4 on growth and limits.

iii) It does not capture other aspects that contribute to our well-being and quality of life such as education, health, infant and child mortality, life expectancy and leisure time.

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[20] Herman Daly in *Resurgence*, issue 269, 2011
[21] Paul Hawken, Commencement address at the University of Portland, May 2009

iv) Empirically, GDP growth can lead to widening inequality – and adverse impacts on social indicators and well-being. The Asian Development Bank's Asia 2012 report[22] highlights a recent example of this, showing that inequality widened in the three countries that have been key drivers of the region's rapid economic growth, China, India and Indonesia. The ADB report notes that with a more even distribution of the benefits of growth another 240 million people would have moved out of poverty in the 45 country region.[23]

v) GDP does not take fully or consistently into account improvements in quality and new goods. This is particularly the case with any big changes in technology. So in the last 20 years the move to a digital and interconnected world is captured differently by different countries depending on the hedonic index[24] that they use. So the role of mobile phones, computers and cameras (often now all in one hand held device compared to two decades ago) is not reflected. Nor are the transformative role of new medicines and medical techniques, keyhole surgery, mapping the human genome, stem cell research, treatment for heart attacks and some cancers, ART for HIV, MRI scanning.

vi) Using a GDP per capita average ignores the distribution of incomes within a country.

A famous campaign speech by Robert Kennedy captures these points[25]:

`Too much and too long, we seem to have surrendered community excellence and community values in the mere accumulation of material things. Our Gross National Product, now, is over eight hundred billion dollars a year, but that GNP counts air pollution and cigarette advertising and ambulances to clear our highways of carnage. It counts special locks for our doors and the jails for those who break them. It counts the destruction of our redwoods and the loss of our natural wonder in chaotic sprawl. It counts napalm and the cost of a nuclear warhead, and armored cars for police who fight riots in our streets. It counts the television programs which glorify violence in order to sell toys to our children.

Yet the Gross National Product does not allow for the health of our children, the quality of their education, or the joy of their play. It does not include the beauty of our poetry or the strength of our marriages, the intelligence of our public debate or the integrity of our public officials. It measures neither our wit nor our courage, neither our wisdom nor our learning, neither our compassion nor our devotion to our country; it measures everything, in short, except that which makes life worthwhile."

[22] `Confronting rising inequality in Asia', Asian Development Outlook, ADB, April, 2012 www.adb.org/publications/asian-development-outlook-2012-confronting-rising-inequality-asia

[23] This argument can be read in revierse. i.e. that inequality is goood for GDP growth so inequality is a good thing. However there is evidence that too much inequality reduces GDP growth.

[24] A price index that uses hedonic regression. This describes how real changes in a product's value can be explained by its characteristics. The US system of national accounts uses hedonics for GDP, providing a boost for GDP figures. But confusingly it also uses hedonics to decrease the Consumer Price Index. In the US in 2003 some US$2.3 trillion of a total GDP of $11 trillion was the result of hedonic pricing. The US is the only major economy to use hedonics, making cross country comparison challenging.

[25] Robert Kennedy, March 16 1968, Campaign Speech in Kansas, 20 years after the UN guidelines were published.

2.2.2 Proposals for and practice of additional or broader measures

As Albert Einstein observed `*Not everything that counts can be measured. Not everything that can be measured counts.'* In response to this recognition there have been several attempts to produce an adjusted or alternative measure to growth of GNP. Some of the leading suggestions include:

i) The Report by the Commission on the *Measurement of Economic Performance and Social Progress*[26], led by Amartya Sen and Joe Stiglitz, with Nick Stern and other luminaries, endorsed by the then President of France Nicholas Sarkozy in 2009 and in a subsequent book, Mismeasuring Our Lives, in 2010[27]

"There is a huge distance between standard measures of important socioeconomic variables like growth, inflation, inequalities etc ... and widespread perceptions. Our statistical apparatus, which may have served us well in a not-too-distant past, is in need of serious revisions."

The Commission looked at three main areas:

1) the limits of GDP as an indicator of progress or economic performance
2) the quality of life, a broader view of wellbeing
3) Sustainable development and the environment

The Commission concluded by recommending that conventional economic statistics and reporting should be supplemented with a much wider range of measures including environmental measures and direct measures of well-being.

ii) A joint EC, EU Parliament, WWF, Club of Rome and OECD report `*Beyond GDP: measuring progress, true wealth and the well being of nations'* was published in 2004. This has led to the ongoing `Beyond GDP' initiative which is developing indicators that are as clear and appealing as GDP, but more inclusive of environmental and social aspects of progress.[28]

iii) The Human Development Index was developed in 1990 as a supplement to the GDP measure. It was created by economist Mahbub ul Haq and based on the work of Amartya Sen. It is the most widely used example of this type. Structurally, it consists of three elements:

1. Standard of living (GDP per capita).
2. Life expectancy at birth.
3. Knowledge: a composite measure of education that includes data on literacy and school enrolment.

In 2010 Amartya Sen observed that *"HDI is people-centered … GDP is commodity-centered.*"
The HDI is one of the UN's key headline indicators, and is considered a useful and meaningful measure of a country's development. Norway has been top of the UN's HDI list

[26] J. Stiglitz, A. Sen, and J-P. Fitoussi (2009) 'Report by the Commission on the Measurement of Economic Performance and Social Progress', p. 9. Available at: http://www.stiglitz-sen-fitoussi.fr/en/index.htm
[27] J. Stiglitz, A. Sen, and J-P. Fitoussi (2010) Mis-Measuring our Lives, Stiglitz, Sen and Fitoussi.
[28] www.beyond-gdp.eu/

since 2000, with the poorest African countries at the bottom. The measure can be refined as Inequality–adjusted HDI to reflect the fact that HDI does not address the distribution issue.

iv) The Index of Sustainable Economic Welfare developed in 1989 by Herman Daly and John Cobb. This index adjusts for the failure to discriminate between goods and bads and thus presents a truer picture. The index includes estimations of the economic cost of many environmental externalities, such as pollution and environmental degradation. A key element is the redefinition of defensive household expenditure (for example, repair bills, medical bills) and expenditure arising from crime and divorce as costs, and therefore as deductions, rather than additions, to GDP.

v) Gross National Happiness[29] a term coined in 1972 by the King of Bhutan as an alternative to GDP. The four pillars of GNH are sustainable development, cultural values, natural environment and good governance. These have then been further classified into nine domains: psychological wellbeing, health, education, time use, cultural diversity and resilience, good governance, community vitality, ecological diversity and resilience, and living standards. There are 33 indicators to measure the equally weighted 9 domains from which the single figure index is constructed. Although there is no exact quantitative definition of GNH, elements that contribute to GNH are subject to quantitative measurement. Low rates of infant mortality, for instance, correlate positively with subjective expressions of well-being or happiness within a country. The indicators include the concept of `sufficiency,' or as Coyle characterises it 'Enough', a concept wholly missing from the GDP measure of growth, where more is always better.

A second-generation GNH concept, treating happiness as a socioeconomic development metric, was proposed in 2006 by Jones, the President of International Institute of Management. The metric measures socioeconomic development by tracking seven development areas including the nation's mental and emotional health. GNH value is proposed to be an index function of the total average per capita of the following measures:

1. Economic Wellness: Indicated via direct survey and statistical measurement of economic metrics such as consumer debt, average income to consumer price index ratio and income distribution, savings
2. Environmental Wellness: Indicated via direct survey and statistical measurement of environmental metrics such as pollution, noise and traffic
3. Physical Wellness: Indicated via statistical measurement of physical health metrics such as severe illnesses and obesity
4. Mental Wellness: Indicated via direct survey and statistical measurement of mental health metrics such as usage of antidepressants and rise or decline of psychotherapy patients
5. Workplace Wellness: Indicated via direct survey and statistical measurement of labor metrics such as jobless claims, job change, workplace complaints and lawsuits
6. Social Wellness: Indicated via direct survey and statistical measurement of social metrics such as discrimination, safety, divorce rates, complaints of domestic conflicts and family lawsuits, public lawsuits, crime rates
7. Political Wellness: Indicated via direct survey and statistical measurement of political metrics such as the quality of local democracy, individual freedom, and foreign conflicts.

[29] www.grossnationalhappiness.com

As Galileo Galilei said "*Measure what is measurable, and make measurable what is not so.*" The trend now appears to be moving towards this approach, developing a more nuanced dashboard style approach, as identified by the EU `Beyond GDP' work and the Sen/Stiglitz/Stern book.

Recent developments in the UK

The UK Department for Environment, Food and Rural Affairs (DEFRA)[30], the Office for National Statistics[31] and the UK Environmental Audit Committee[32] have all launched consultations or surveys into measures of well-being.

For example, the Sustainable Development Indicators developed by DEFRA include the following measures:

- Economic prosperity
    - GDP, GDP per head, and equivalised median (middle) household income before housing costs.
- Long term unemployment
    - Percentage of people who have been out of work for more than 12 months.
- Poverty
    - To be identified – taking into account the Social Mobility Strategy, the Child Poverty Strategy and the Office for National Statistics' measures of national wellbeing.
- Knowledge and skills
    - The value of knowledge and skills (as a proxy for human capital) per person of working age.
- Healthy life expectancy
    - Healthy life expectancy.
- Social capital
    - To be developed.
- Social mobility in adulthood
    - Proportion of working-age population employed in higher-level occupations by social background (defined using father's occupational group).
- Housing provision
    - Net additions to the housing stock (new dwellings).
- Greenhouse gas emissions
    - Greenhouse gas and carbon dioxide emissions generated within the UK.
- Natural resource use
    - Raw material consumption in non-construction sectors and GDP – experimental data.
- Wildlife and biodiversity
    - Wildlife: Bird population indices – farmland birds, (b) woodland birds, (c) seabirds and (d) water and wetland birds (this measure may be adjusted or clarified).
- Water availability
    - To be identified.

[30] http://sd.defra.gov.uk/new-sd-indicators/
[31] http://www.ons.gov.uk/ons/dcp171766_272242.pdf
[32] http://www.parliament.uk/business/committees/committees-a-z/commons-select/environmental-audit-committee/news/new-inquiry-measuring-well-being-and-sustainable-development/

In February 2012 the UK has released the first analysis on the new well being measure developed by the Office for National Statistics.[33] This report opens with the statement:

`It is increasingly understood that traditional economic measures are necessary, but not sufficient, to reflect a nation's overall progress or well-being. There has been increasing interest in the UK and around the world in using wider measures of well-being to monitor progress and evaluate policy in order to focus on quality of life and the environment, as well as economic growth in assessing progress.'

Australia already does something similar through Measuring Australia's Progress (MAP) with four categories: individuals, the economy, the environment and living together. Canada and Germany have indexes of Well Being, the OECD has a Better Life Index. This scores 11 elements: housing, incomes, jobs, community, education, environment, civic engagement, health, life satisfaction, safety, work-life balance. This set of indicators looks very similar to the now 40 year old Bhutan measure.

The OECD Better Life ranking is shown below:

[33] www.ons.gov.uk/ons/rel/wellbeing/measuring-subjective-wellbeing-in-the-uk/analysis-of-experimental-subjective-well-being-data-from-the-annual-population-survey--april---september-2011/report-april-to-september-2011.html

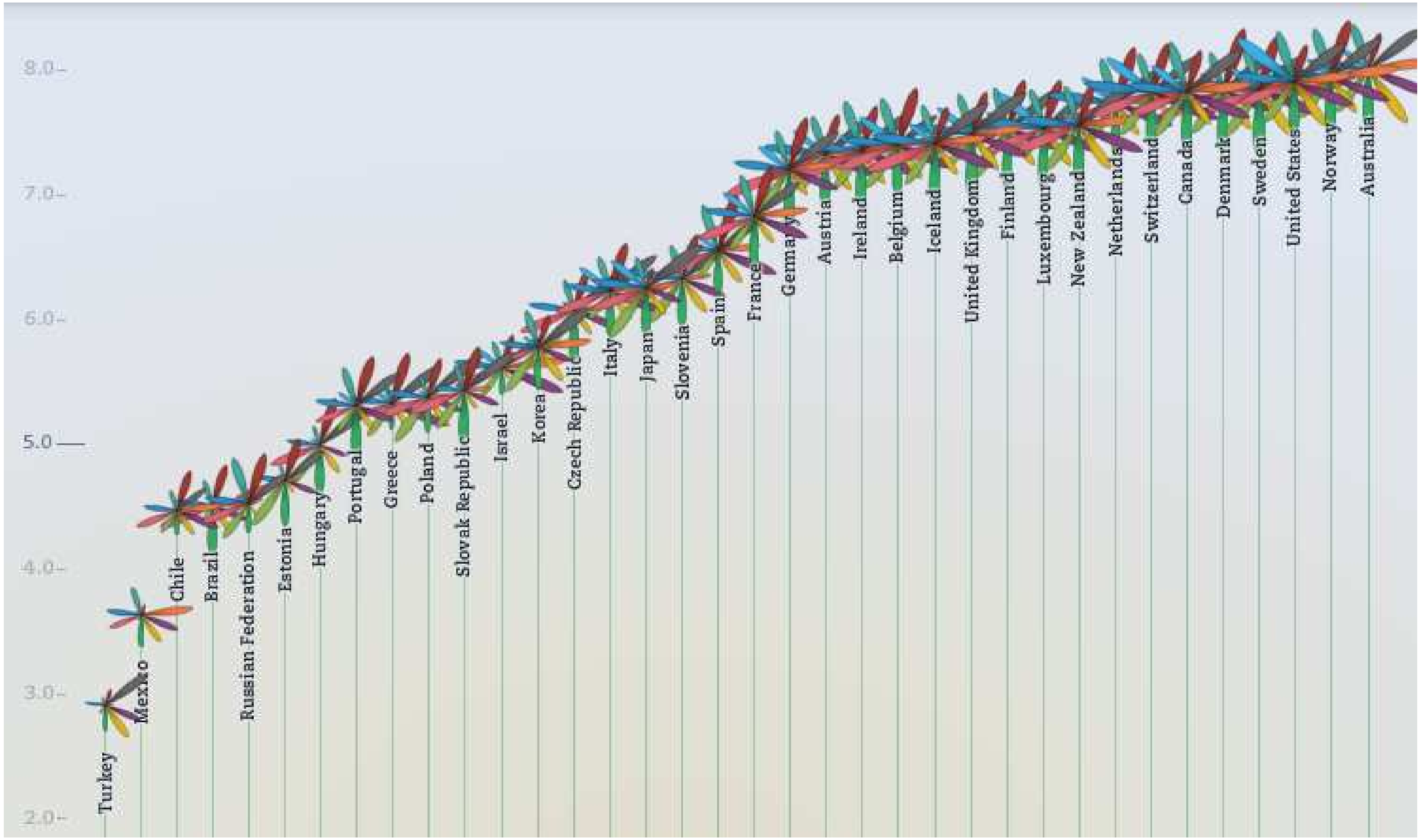

Figure 4: OECD Better Life Index (retrieved 23/05/12 http://www.oecdbetterlifeindex.org/#/11111111111)

2.2.3 Small numbers, big impacts

It is helpful to be aware that what can at first appear to be low or small rates of growth, e.g. a 2% annual increase, can have large impacts over long periods of time, as with the US GDP per capita which has grown at an exponential rate of 2% pa for the last 200 years. This is due to the power of exponential growth, with its classic hockey stick curve. A growth rate of 2.5% per annum leads to a doubling of GDP within 29 years, whilst a growth rate of 8% per annum (a rate met or exceeded by China between 1998 and 2010) leads to a doubling of GDP within 10 years. The challenge of exponential growth of GDP is that the amount that is added grows larger each year. The outcome is "speeding up" the use of finite resources that each country needs to keep its GDP measure of production growing. Taken globally this puts huge pressure on all resources as the compound impacts grow ever larger in a finite world.

Ruchir Sharma[34] highlights that the richer a country is, the harder it is to grow national wealth at a rapid pace. This is now China's position. Very few nations are able to achieve long term rapid growth. Sharma's whole premise is about searching out where the best growth rates are to come from in the years ahead, recognising that this is becoming harder. He identifies smaller economies starting from a lower base as those with most potential now as *`China is on the verge of a natural slow down…. in 1998 for China to grow its $1 trillion economy by 10% it had to expand its economics activities by $100 billion and consume 10% of the worlds industrial commodities (oil, copper, steel). In 2011 to grow its $6 trillion economy that fast it needed to expand by $600 billion pa and consume 30% of the worlds industrial commodities.'* Even at a 5-6% growth rate China will remain the largest single contributor to global growth in the years ahead. An annual growth rate per country can lull the reader in a false sense of what is possible or desirable. Growth at 2% pa from 2050 to 2100 would mean a global economy 40 times the size of the economy in 2009[35]. Or as the Limits to Growth: The 30 Year Update succinctly put it *`often a declining growth rate still produces a rising absolute increment, when a smaller percentage is multiplied by a much larger base.'*

2.3 Growth and Debt

2.3.1 Importance of growth to a debt based system

Some history

There is a long history of borrowing (whether by governments, individuals or firms), together with an historical prejudice against it, whether expressed in the Bible or as captured by Shakespeare in Hamlet *`Neither a borrower nor a lender be; For loan oft loses both itself and friend, And borrowing dulls the edge of husbandry.'*

Borrowing by governments is usually for three main reasons: for investment, for war or for consumption. In the US in 1949 there was a policy disagreement amongst the Council of Economic Advisers to the President about the choice to be made between "guns or butter." Those favouring borrowing for consumption argued that an expanding economy (i.e. growth) permitted large defence expenditures without sacrificing an increased standard of living. So the either /or dilemma on war/consumption was neatly avoided because of growth. Those against resigned, warning about the dangers of budget deficits and increased funding of "wasteful" defence costs[36].

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[34] Ruchir Sharma *Breakout Nations, 2012*
[35] Tim Jackson *Prosperity without Growth, 2009*
[36] Edwin Nourse, Chairman, Council of Economic Advisers to President Harry Truman

Current practice
The conventional wisdom has shifted now, so that growth is required *in order* to at least service debt. This goes hand in hand with an understanding that with increased productivity, employment will reduce over time without growth. This means that the challenge of transition to a low growth economy has these two aspects to overcome.

Since the late 1960s the US has run a deficit, however although national debt grew, its percentage of the growing US economy did not increase rapidly. But since the 1970's actuaries in the US have warned that given the aging of the baby boomers, a fiscal crunch would occur in America sometime between 2010 and 2020s. The Clinton administration's economic policies were designed in part to generate budget surpluses that could pay off the deficit before the baby boomers retired and began to draw on Social Security and Medicare. As a result from 1993 to 2001 America's debt:GDP ratio went from 49% to 33%. However this policy decision was reversed by the incoming administration of George W Bush. By 2011 debt was equal to GDP at some $14 trillion. By 2012 it reached 119% of GDP: `*We are outer edge of 200 years of experience*'[37] as we are enter new territory on how much debt an economy can handle.

In *Breakout Nations* Sharma compares countries' debt indicators as a means of assessing their breakout potential or the reverse, their vulnerability. He highlights that in India total public debt to GDP is 70% , one of the highest for any major developing country. In China official government debt is low at some 30% of GDP but the debt of companies and households is some 130% of GDP, among the highest levels in emerging markets. This is partly because Beijing ordered banks to issue a huge expanse in credit in response to the 2008 crisis. If shadow banking is included the ratio of debt:GDP rises to 200% - `*levels unseen before, fueling a consumption boom.'*

Overall he suggests that `*the liquidity fueled turbo charged boom of the last decade, ..is now unraveling as the cost of funding growth rises'* whilst observing that `*never have so many nations grown so fast for so long as they did in the last decade*.' He suggests that the era of debt fuelled growth is now coming to an end and suggests that `*failure to sustain growth is the general rule, and that rule is likely to reassert itself in the coming decade.'*

Instability
This analysis is also reinforced by Coyle who posits that `*market economies are unstable'* with `*constant vulnerability to boom and bust'* whether the e.g. mid 1970s OPEC oil price spike or 2008 near collapse of global financial system. She suggests that in mature (developed) economies, economic policy has `*borrowed from the future on a significant scale, both through the accumulation of debt in order to finance consumption now, or through the depletion of natural resources and social capital*. 'The 2008 financial crash was `*an indication of a system wide failure*.'

This reasoning is even further developed by Reinhart and Rogoff in their book *This Time is Different*: *eight centuries of financial folly* by highlighting the belief by the markets that, this time, there will not be a crash, only for there to be a crash. Learning from debt crises, whether sovereign external debt, domestic debt, banking crises, inflation and modern currency crashes or the most recent sub prime crisis their empirical analysis covers 66 countries over nearly eight centuries and finds a `*near universality of default'* in sovereign external debt.

[37] T. Friedman and M. Mandelbaum*, That Used To Be Us*, 2011

They highlight that the US exhibited all the standard indicators of a country on the verge of a financial crisis prior to the 2008 crash. They find that on average government debt rises by 86% in the three years following a banking crisis. *`Again and again countries, individuals, and firms take on excessive debt in good times without enough awareness of the risks that will follow when the inevitable recession hits.'* They highlight *`the strong connection between financial markets and real economic activity, particularly when financial markets cease to function.. has made so many of the crises.. such spectacular historic events.'* In contrast the collapse of the Dot.com bubble in global stock market in 2001 was largely confined to technology stocks and the effect on the real economy was a relatively mild recession. *`Bubbles are far more dangerous when they are fueled by debt, as in the case of the global housing price explosion of the early 2000s.'*

Super interconnectedness
What is different this time is the super interconnectedness of the global system, with fragile highly leveraged economies, with a concomitant vulnerability to market crises of confidence, as we are witnessing now in the Eurozone.

Reinhart and Rogoff suggest that we are now in `the Second Great Contraction.'[38] They urge that going forward there is a need for much better cross country data on debt covering long time periods, also debt held by consumers, banks and corporates. Banks have had a changing role in the creation of credit and debt-based growth in recent years, enabling growth and the rise of consumption through increased debt to new very high levels, as we have seen in countries as diverse as China, the USA and the UK. Recent events have now led to calls for financial sector reform as a result of a number of scandals and challenges with this approach.

Reinhart and Rogoff suggest that there is a role for multilateral finance institutions, such as the IMF, in both gathering and monitoring data. They propose a new independent international institution to develop and enforce international financial regulations. (Particularly so that such regulation is independent of national political pressure). However such a call is predicated on belief in the effectiveness of such institutional approaches in the past. In the complex, non-linear systems that we have now, this may not be an appropriate response, even supposing such an institution could effectively play the role of an enforcer. We have seen how rapidly crisis and collapse can emerge e.g. in the US, Iceland, in Greece and the risk of contagion and market sentiment.

Uncertainty
In times of uncertainty globalised highly efficient and standardised economic systems are vulnerable to shocks, as recent events show, with high risk of contagion due to interconnectedness of systems. There is therefore a need to build in diversity, buffers and redundancy; to promote and enhance resilience. Resilience indicators are increasingly being used to measure the 'health' of systems (ecological; social; economic) rather than a focus on growth. We will return to this point later in this chapter.

[38] The Great Contraction was a term coined by Friedman & Schwartz in 1963 to depict the 1930s Great Depression. Contraction covers the wholesale collapse of credit markets and asset prices together with contracting employment and output (GDP).

2.3.2 Different macroeconomic approaches to debt

Approaches to debt and growth vary depending on the choice of macro economic policy, leading to different policy choices. These can be very broadly characterised as follows:

1. Growth is the solution
    a. austerity (often associated with monetarism[39]);
    b. prosperity through growth (Keynesian, using borrowing to maintain growth in a downturn);
2. Green growth (green new deal);
3. End of growth (prosperity without growth, ecological economics; steady state)

A detailed review of different narratives around these approaches to future growth within the context of resource constraints by various commentators will be undertaken in the next chapter.

Growth, investment and innovation

There is an ongoing debate over the role of growth in enabling investment, including investment in innovation. Pro growth innovators posit that we need growth in order to finance the necessary investment in innovation to take us forward. This is particularly true of those who advocate that 'technology' will solve many of the pressing food, water, energy and climate challenges. They suggest that the scale of resource efficiency required by prosperity without growth will require huge investment in technology that in turn can only be financed and incentivised through a growth economy.

Neo-Schumpeter arguments about boom and bust and phases of innovation are pertinent here. i.e. that the series of crises that the world economy is now in, are not a sign of systemic failure or default of the system, rather a consequence of its enormous success, with necessary cycles of boom and bust a normal part of this. A risk-taking entrepreneur, acting on the basis of innovation and future oriented strategies, is necessary for the creation and implementation of new goods and services in markets. So capitalism is a system to a high degree linked to uncertainty and insecurity, in both a positive and negative sense. Everything can and will happen in such a system if unregulated. It is capable of generating impressive performances and also of causing painful collapses. It is, therefore, not a system of balance and harmony, but one which swings between possible extremes of the highest success and the deepest crisis. Schumpeter referred to this as `creative destruction.'

More attention and research could be given to the possible role of growth in enabling the necessary significant investment in innovation.

[39] Its advocates see monetarism as a way of promoting growth

2.4 Growth and Limits – a shift in the narrative

2.4.1 The Steady or Stationary State

History teaches us that earlier economists from Adam Smith to JM Keynes believed that growth would be a transitional stage and we would then be able to move to a steady or stationary state economy[40]. Adam Smith reasoned that all economies would eventually reach `a stationary state' when they had *`acquired that full complement of riches which the nature of its soil and climate, and its situation with respect to other societies allowed it to acquire, which therefore advance not further and which was not going backwards[41].'*

John Stuart Mill stated that *`the increase in wealth is not boundless. The end of growth leads to a stationary state. ..It is scarcely necessary to remark that a stationary condition of capital and population implies no stationary state of human improvement. There would be as much scope as ever for all kinds of mental culture, and moral and social progress, as much room for improving the Art of Living and much more likelihood of its being improved, when minds cease to be engrossed by the art of getting on.'*

Paul Gilding predicts a failure of growth, with desperate attempts to restart growth, followed by a recognition that the end of growth is being caused by hitting the planet's physical limits. Hence the need `*to design an economy that is rich in progress and increasing prosperity, but not destructive in physical impact.*' This could include a cap and trade system on key resources, shifting the burden of taxation from things we want more of (e.g. jobs) to things we want less of (e.g. pollution, overuse of finite resources). There are a number of other similar proposals, for example, from nef, from Tim Jackson and from the Center for the Advancement of the Steady State Economy (CASSE)[42].

As Herman Daly has commented: *The closer the economy approaches the scale of the whole earth the more it will have to conform to the physical behaviour mode of the Earth. That behaviour mode is steady state – a system that permits qualitative development but not aggregate quantative growth.[43]*

Herman Daly has long maintained that `*Uneconomic growth – the quantative expansion of the economic subsystem increases environmental and social costs faster than production benefits, making us poorer not richer, at least in high consumption countries.'*

A more conservative proposition comes from Friedman and Mandelbaum for `sustainable economic growth' in *That Used to Be Us*. They posit that the US needs to cut spending, increase revenues and invest in the future all at the same time. `*It may be possible to grow effectively without a plan but there is no way to shrink effectively without a plan.'*

2.4.2 Limits to Growth

As referred to in section 2.1.2 the limits to growth were explored in the book reporting to the Club of Rome of the same name in 1972, in the 30 Year Update in 2004 and most

[40] Although, interestingly, if we go back further than Adam Smith, we find that the economic doctrine of mercantilism viewed government control of foreign trade of great importance for ensuring prosperity and security. (16th to late 18th centuries)
[41] Adam Smith *`An enquiry in the nature and causes of the Wealth of Nations'*, 5th ed.
[42] www.steadystate.org
[43] Herman Daly *A Steady-State Economy*, commissioned by the SDC, April 14th 2008

recently in 2052[44]. The 1972 Limits to Growth reported that global ecological constraints (related to resource use and emissions) would have a significant influence on global developments in the 21st Century. It developed the World3 model to simulate interactions, with five variables (world population, food production, industrial output, pollution and resource depletion) and three scenarios. It found that in two of the three scenarios overshoot and collapse occurred by the mid to latter part of the 21st century. A third scenario resulted in a stabilised world.

The *2004 30 year Update* highlighted that *`absolute global rates of change are greater now than ever before in the history of our species. Such change is driven mainly by exponential growth in both population and the material economy. Growth has been the dominant behaviour of the world socio economic system for more than 200 years.'* The 30 Year Update presented 11 possible scenarios for the future to 2100. Early scenarios show a tendency to overshoot and collapse and in the last 4 scenarios the modelling assumes deliberate action is taken to stabilise one or more of the variables in order to avoid this.

The model used in *2052* provides the following key messages:

- The global population will stagnate earlier than expected because fertility will fall dramatically in the increasingly urbanised population. Population will peak at 8.1 billion people in 2040 and then decline.

- The global GDP will grow more slowly than expected, because of the lower population growth and declining growth rates in (gross labour) productivity. Global GDP will reach 2.2 times current levels in 2050.

- Productivity growth will be slower than in the past because economies are maturing, because of increased social strife, and because of negative interference from extreme weather.

- The growth rate in global consumption will slow because a greater share of GDP will have to be allocated to investment – in order to solve the problems created by climate change, resource scarcity, and biodiversity loss. Global consumption will peak in 2045.

- As a positive consequence of increased investments in the decades ahead (albeit often involuntary and in reaction to crisis), resource and climate problems will not become catastrophic before 2052. But there will be much unnecessary suffering from unabated climate damage in the generations around the middle of the century.

- The lack of a dedicated and forceful human response in the first half of the 21st century will put the world on a dangerous and unstoppable track towards self-reinforcing global warming in the second half of the 21st century.

- Slow growth in per capita consumption in much of the world (and stagnation in the rich world) will lead to increased social tension and conflict, which will further reduce orderly productivity growth.

[44] *The Limits to Growth*, Meadows, Randers & Meadows 1972, *The Limits to Growth: The 30 Year Update*, Meadows, Randers and Meadows 2004, and *2052: A global forecast for the next 40 years*, Jorgen Randers, 2012.

- The short term focus of capitalism and democracy will ensure that the wise decisions needed for long term well-being will not be made in time.

- The global population will be increasingly urban and unwilling to protect nature for its own sake. Biodiversity will suffer.

- The impact will differ between the five regions analysed in the book:
  1. US
  2. OECD, less US (the rest of the industrialised world)
  3. China
  4. BRISE (Brazil, Russia, India, South Africa and 10 other big emerging economies)
  5. Rest of the World (the 2.2 billion people at the bottom of the income ladder).

- The current global economic elite, particularly the US, will live with stagnant per capita consumption for the next generation. China will be the winner. BRISE will make progress. The Rest of the World will remain poor. All – and particularly the poor – will live in an increasingly disorderly and climate damaged world.

- The world in 2052 will certainly not be flat, in the sense of being a level playing field with equal opportunity and connectedness[45].

2.5 The New Growth?

2.5.1 What is growth for?

Some earlier economists[46] have recognised that the optimum or desirable rate of growth is not the maximum possible growth now, but rather growth that takes due account of the future, including the future health of the economy. The big question posed by Diane Coyle was *`How to run the economy as if the future mattered?'* Or as Limits to Growth: the 30 year update asked - *`Growth of what? For whom? At what cost? Paid by whom? What is the real need here and what is the most direct and efficient way for those who have the need to satisfy it? How much is enough? What are the obligations to share?'*

A consultation with over 400 business leaders asked them to explain the purpose of a good economy[47]. Their response was *"The fundamental purpose of a good economy is to steadily improve the well-being of all people, now and in the future, with due regard to equity, within the constraints of nature, through the active engagement of all its participants."*

They identified 10 attributes of a good economy:

Fulfilling	Inclusive
Farsighted	Developing
Equitable	Participatory
Innovative	Sustainable
Diverse	Accessible

[45] A reference to Tom Friedman's book *The World is Flat: a brief history of the 21st century*
[46] Frank Ramsey, Partha Dasgupta
[47] The Sustainable Economy Dialogue: Report and Reflections, CPSL 2006

They also identified 10 failings of current economies as follows:

Failing	***Description***
Lack of education	There is a lack of education and awareness around the links between the economy and sustainability
Governance failings	Governments and institutions are ineffective in providing good governance and appropriate policies
Short-term focus	Political processes, economic pressures and financial markets prejudice against long-term thinking
Unfair distribution	The economy creates and maintains inequity in opportunity, power, wealth and wellbeing
Human weakness	Traits such as selfishness and greed are encouraged and exacerbated by the capitalist system
Inappropriate incentives	Market failure and protectionist interventions create incentives for unjust and unsustainable trade
Cost externalisation	Prices fail to capture social and environmental costs and therefore undervalue people and nature
Divided purpose	There is a lack of collective consensus on the long-term purpose of the economy
Unsuitable values	The values underlying the current economic system may be incompatible with sustainability
Misleading measures	Current economic measures are poor indicators of quality of life, social wellbeing and environmental integrity

2.5.2 Green growth or low carbon, climate resilient growth

As Joseph Stiglitz succinctly observed *"GDP tells you nothing about sustainability."*
New characterisations of growth move beyond the simple measure of increasing GDP and towards a more balanced view, that is closer to what has been called sustainable development. If growth is "quantitative increase in the physical dimensions of the economy," that is, producing more and more, then sustainable development suggests a more balanced `qualitative improvement' across a range of indicators. The conventional definition from the 1987 Brundtland Commission is development that *"meets the needs of the present without compromising the ability of future generations to meet their own needs*.' A new, simpler, shorter version is `*Enough, for all, forever.*' [48]

This newer version of growth has been called `green growth' or even more recently and specifically  `low carbon, climate resilient growth.' It has strong advocates from the Grantham Research Institute, led by Lord Stern and the South Korea based Global Green Growth Institute and the World Bank. As Stern has stated:

`We can and must, now and simultaneously, handle the short-term crisis, foster sound development and economic growth in the medium term, and protect the planet from devastating climate change in the long term. To try to set the three tasks against each other as a three-horse race is as confused analytically as it is dangerous economically and environmentally. In particular, the developed world must demonstrate for all, especially the developing world, that low-carbon growth is not only possible, but that it can be a productive, efficient and attractive route to overcome world poverty. It is indeed the only sustainable route. '

[48] Professor Paul Younger, Newcastle University campaign for sustainability, 2012

The World Bank have recently joined the queue endorsing the concept of Inclusive Green Growth in a new policy paper[49]. This states that `*Inclusive green growth is **the** pathway to sustainable development. Green growth also requires improved indicators to monitor economic performance. National accounting indicators like GDP measure only short-term economic growth, whereas indicators like comprehensive wealth—including natural capital—help us determine if growth is sustainable in the long run.'*

Brazil, Cambodia, Ethiopia, Indonesia, Kazakhstan, Thailand and the UAE are working on their own plans with the help of the GGGI and work is planned in Yunnan Province in China, Mongolia, Philippines, Rwanda and Vietnam[50]. Countries as diverse as the EU and India are pursuing policies with strong green growth elements. Even if they are not, they are labelled as such, such is the popularity of the term. The World Bank identifies the four channels for green growth as input, efficiency, stimulus and innovation effects. The GGGI suggests that the four keys to success are institutionalisation, technology, capacity building and financing.

2.5.3 Technologically led innovations

Resource efficiency will play a more important role over the next decades. A recent report by McKinsey has explored this in more detail[51]. Their analysis suggests that there are resource productivity improvements available that would meet nearly 30% of demand for resources in 2030.

McKinsey have delivered aspects of this message before, for example in a 2009 report *Unlocking energy efficiency in the US economy* it stated that ` *If serious but affordable energy efficiency measures were implemented through out the US economy through 2020 this would yield gross energy savings worth $1.2 trillion (>x2 the $520bn investment in such measures needed in that time frame. So energy efficiency would save x2 what it cost).* '

In *Prosperity without Growth* Tim Jackson makes clear that it is important to distinguish between relative and absolute decoupling. In relative decoupling resource impacts decline *relative to GDP*, but not absolutely. So impacts still increase, but at a slower rate than the growth in GDP. For impacts to decline absolutely there is a need for absolute decoupling. This is much harder to achieve.

The Ehrlich or IPAT equation explains the relationship between absolute and relative decoupling. The IPAT equation tells us that the impact (I) of human activity is the product of three factors: the size of the population (P), its levels of affluence(A) and the technological intensity of economic output (T). I=PxAxT. As long as T is going down we can get relative decoupling. However for absolute decoupling I needs to fall as well, and for this we need T to outstrip any increases in P and A.

P and A have both been increasing over the last decades. Addressing population growth has been a tricky political issue (although both India and China have tried) and increasing levels of affluence have been widely interpreted as the route to increased wellbeing until recently, as discussed earlier. Hence the deep attachment to T - the idea that `technology will fix it.'

If significant investment in technology innovation is seen as a consequence of resource constraints and a true absolute decoupling is possible then technology led solutions to the

[49] http://siteresources.worldbank.org/EXTSDNET/Resources/Inclusive_Green_Growth_May_2012.pdf
[50] Green Growth Planning, GGI Country Programmes, 2012
[51] *Resource Revolution: Meeting the world's energy, materials, food and water needs*, McKinsey Global Institute & McKinsey Sustainability and Resource Productivity Practice, November 2011

'*limits to growth'* will be increasingly important.

2.5.4 Socially led innovations

Much of the attachment to growth derives from the belief that with growth comes increasing prosperity for all of us. In fact as the Limits To Growth: 30 year update observes *`Growth as usual has widened the gap between rich and poor. Continuing growth as usual will never close that gap. Only changing the structure of the system will do that.'*

Conventional economic growth is concerned with efficiency, how to maximise the income produced for a given quantity of inputs. Equity is seen as a separate factor. If the purpose of the economy were redefined as increasing well-being, rather than increasing growth (more goods and services), then equity would become another dimension of efficiency.

If economic efficiency is about how inputs are translated into production, equity is about how efficiently that total production is translated into quality of life.

The conventional wisdom on short term inequality as a necessary condition of growth, that will trickle down to the poorest eventually, has been upset by the work of Wilkinson and Pickett in The Spirit Level.[52] This finds that, across a range of indicators in 23 rich countries, equality is better for everyone. This includes outcomes such as life expectancy, infant mortality, physical and mental health, education, crime, safety, social mobility, debt, hours worked, recycling. They also found that more equal societies are more innovative, thus helping with the T in the IPAT relationship, as well as the A.

2.6 Conclusion

There is significant attraction and traction to the green growth path. However the limits of this approach are apparent depending on the weight given to the earlier arguments introduced in this chapter, such as ecological and social boundaries, the role that inequality plays and the actual objective of growth. Is it higher levels of well being for more people, enough for all forever, or simply more production for more profit and increased wealth for a few?

The time frame for these decisions is important. Increasingly evidence suggests the overwhelming importance of living within planetary and social boundaries. These are not linear limits, but tipping points beyond which the system shifts into more unstable and undesirable states which are not susceptible to modelling or management. This has resonance with actuarial work around risk and uncertainty as it introduces the precautionary principle through the recognition of safe operating limits and is consistent with current scientific and economic thinking.

T.S.Eliot warned
`Growth will be at the expense of future generations, but it makes the GNP numbers look good today'.[53]

[52] R Wilkinson & K Pickett*, The Spirit Level: Why equality is better for everyone*, , 2 ed. 2010
[53] T.S Eliot *Christianity and Culture*, 1949

3. Current discourse on Limits to Growth

In 1972, the *Club of Rome* argued that unchecked growth, of people and economy, was placing impossible strain on our finite planet.[54] Our way of life was bumping up against non-negotiable, biophysical 'limits to growth', or ecological constraints, pushing human civilization towards possible collapse. As a result, at the very best, humanity could look to a globally managed, orderly and smooth adaptation to growth's demise. This projection was based at the time on the perception that humanity was at risk of 'overshooting' the earth's carrying capacity, or exceeding the planet's ability to meet human demand for its resources and ecosystem processes.

Since the original 1972 report, when it was thought that there was still some room available for both global population and economy to grow, and thus time to avert dangerous trends, the human ecological footprint has continued to expand. By the 1980s, this scenario was no longer a 'risk' but a reality, when human demand surpassed earth's ability to supply for the first time.[55] By 1999, this "overshoot" was some 20% above the global carrying capacity.[56] In 2007, according to the WWF Living Planet Report, it reached 50%.[57] Natural resource declines are unavoidable; technology can only briefly postpone it – unless technology manages to change, radically, our current dependence on resources.

The issue of surging demand for natural resources, (since 1966, humanity's "Ecological Footprint" has doubled[58]) is not immediately running out of fossil fuels, or important metals and minerals, but reaching a point when, thereafter, extraction becomes more costly. In the end society must begin to divert so much of its financial resources to maintaining current volumes of production and consumption that less remains to deal with everything else.

An additional "limit to growth" is the rising negative environmental and social impacts associated with growing extraction, use, and disposal of resources, including increasing carbon emissions, water pollution, deforestation, soil depletion, biodiversity loss and human health issues, simultaneously inflicting greater intrinsic economic costs as well as becoming more expensive to manage and mitigate via damage-control efforts.

The current economic crisis has reinvigorated the debate on "Limits to Growth". How are we to halt the rate of species extinction, meet the consumer aspirations of a burgeoning middle class in emerging markets, ensure food and energy security for a global population of potentially 9 billion? This chapter examines a range of the most recent and discussed opinions put forward by thought leaders, governments, academics, the private sector and NGOs, each with their own perspective on how, when and why limits may or may not encroach on future prosperity and planetary wellbeing and what growth's fate ought to be in this equation.

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[54] Donella Meadows, Jorgen Randers, Dennis Meadows and William W. Behrens III, *The Limits to Growth*. (New York: Universe Books, 1972)
[55] Donella Meadows, Jorgen Randers and Dennis Meadows, *Limits to Growth: The 30-Year Update*, (London: Earthscan, 2010) p. xv
[56] Ibid
[57] WWF, *Living Planet Report 2010: Biodiversity, biocapacity and development*, (Switzerland: WWF International, 2010) p. 8. <http://assets.wwf.org.uk/downloads/wwf_lpr2010_lr_1_.pdf> [Accessed Feb 2012]
[58] Ibid – the Ecological Footprint is a measure of the area of productive land and sea required to meet the consumption and waste of the human population.

The responses can be grouped around four broad themes which are related to the macroeconomic approaches to debt outlined in the previous chapter (although here we include beyond the limits – negative growth – as a new theme):

1) Growth is the solution
2) Green growth
3) End of growth
4) Beyond the limits.

Interestingly there is little commentary around 'unlimited' resources (that we will just be able to increase supply to meet our future demand).

3.1 Growth is the solution

In his history of macroeconomics, Angus Maddison (2007) analyses the reasons why some parts of the world have become wealthy and others have fallen behind.[59] Taking a tour through 2000 years of history, Maddison traces the rise and fall of various empires, from Rome, through to the eastern empire, through to the rise of the West , the transformation of the Americas, and the conquest and collapse of colonialism. The second part of the book is devoted to examining the development of macro-economic measurement and the schools of thought surrounding modern economic growth and from whence it came. Of interest to this review are Maddison's projections for the future of growth up until 2030.

He takes the view that the momentum of modern growth is such that it will continue, along with CO_2 emissions and increases in per capita income. He predicts that between 2003 – 2030 we will experience the fastest growth rate in history of per capita income, (except in the "golden age" period of 1950 – 1973), of 80% and a 2.25-fold increase in global GDP, along with increases in life expectancy, a fall in birth rates, and greater convergence between advanced and emerging economy consumption levels.[60] Growth will be the dominant theme, with events taking place that either deviate or continue this overarching trajectory.

Although he agrees that energy shortages, political developments and attempts to limit emissions might be hindrances to his growth scenario, (the "potential long-term threats" of global warming "would require coordinated global action to prevent them happening" but he stresses that "there would be major problems in deciding now on expenditure to benefit future generations and in dividing costs between countries at widely differing levels of income"[61]) he argues that in Europe the positive features of climate change will outweigh the negative, rich countries have "greater capacity to cushion negative impacts by adaptive policy action", and that future generations will have much higher incomes so will be able to deal with the consequences.[62] He argues that there have been repeated warnings concerning natural resource limits in the past, from Malthus to Jevons to the Club of Rome, which have thus far proved faulty and alarmist. Technical progress, capital formation and international specialisation have enabled humanity to avoid the calamities that these "ecodoomsters"[63] portray. He assesses the Intergovernmental Panel on Climate Change (IPCC) *Special Report on Emissions Scenarios (SRES 2000)* and the Stern Review on the

[59] Angus Maddison, *Contours of the World Economy, 1 – 2030 AD: Essays in Macro-Economic History*, (Oxford: Oxford University Press, 2007)
[60] Ibid, p.6
[61] Ibid, p.362
[62] Ibid, p.361
[63] Ibid, p.352

Economics of Climate Change, expressing reservations about both the IPCC's quantifications of its scenarios and the urgent tone of the Stern Review, but supporting the latter's general recommendations for emissions reductions as "pragmatic, prescriptive and persuasive"[64]. Maddison concludes by arguing that

> *"In spite of the scepticism about the higher IPCC scenarios for the twenty-first century, and the doomsday outlook beyond that point, it would be a mistake to dismiss the likelihood and implications of a milder degree of global warming. Proven reserves of fossil fuels are in any case likely to be inadequate to sustain the growth potential of the world economy to the end of the present century, so it would seem sensible to reduce dependence on them and encourage research on and development of alternative sources of energy."*[65]

It would seem that Maddison views natural resource and ecological limits as bumps in the "epoch of modern economic growth"[66], manageable by technical innovation and prudent international policy. This is clear in his view and treatment of Western history as a "long apprenticeship"[67] to modern economic growth.

Matt Ridley (2010) is perhaps more triumphant in his perspective on the future promised by growth, as explored in his book *The Rational Optimist*.[68] Like Maddison, Ridley interprets history through an economic lens but is distinctly bolder in explicitly ascribing a meta-narrative of Darwinian progress to its evolution, characterising man as "an ever-expanding progressive moderniser"[69]. His view is that growth has delivered great benefits to humanity and will continue to do so – indeed must. His argument is presented as both analytically evidence-based and morally just. Ridley is the self-styled "rational optimist" battling conventional wisdom, which seeks to dismantle growth's achievements in the form of unfounded "apocalyptic pessimism"[70].

Ridley seeks to persuade us that growth offers the way to human happiness and wellbeing pointing to humanity's growth-induced success stories – increased average life expectancy, greater economic and personal freedom, hugely expanded agricultural productivity, declining global income inequality, rising real income, improved global literacy rates, cleaner air and generally greater abundance of ever cheaper goods, services and necessities, such as food, clothing, fuel and shelter, leaving more money and time for consumption of luxuries and leisure activities. In short the world is "richer, healthier and happier"[71] than ever before and this trend, the "relentless upward march of human living standards"[72], is set to continue thanks to growth's ability to surmount any impending limits. His analytical argument against the counter view can be summed up as a confidence in humanity's ability to reinvent and adapt itself to new challenges, as it has done in the past, based on the increasing specialisation and exchange of ideas between individuals, or the continued expansion of capitalist economic growth. Limits can thus be overcome through innovation and inventiveness – humanity's limitless resources for change.

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[64] Ibid, p.364
[65] Ibid, p.366
[66] Ibid, p.315
[67] Ibid, p.6
[68] Matt Ridley, *The Rational Optimist: How Prosperity Evolves*, (London: HarperCollins, 2010)
[69] Ibid, p.4
[70] Ibid, p.352
[71] Ibid, p.10
[72] Ibid, p.32

Ridley speaks also to our ethical sensibilities, as the limitations a pessimistic outlook manifests on human progress. To prevent change, innovation and growth is to stand in the way of potential compassion."[73] In other words, the state of the world makes "ambitious optimism…morally mandatory"[74]. Ridley's argument is here seemingly founded as much on faith and belief – or hope – as any rational calculation and weighing up of the evidence. Ridley concedes that "the pessimists are right when they say that, if the world continues as it is, it will end in disaster for all humanity"[75]. But stresses that "the world will not continue as it is… That is the whole point of human progress, the whole message of cultural evolution, the whole import of dynamic change – the whole thrust of this book"[76]. Rather, the human race has become a collective problem-solving machine and therefore confronts those problems, such as resource and ecological limits, through changing its ways by invention, usually driven by scarcity in the market, as has often been the case in history. While Ridley makes the charge against pessimistic environmentalists that their view is simply blind extrapolation of the past projected into the future, he is possibly making the same mistake by assuming that because humans have adapted and changed to overcome limits in the past, they will not fail to do so in the future.

For Ridley, Malthusian limits are false. In the penultimate chapter Ridley examines the "two great pessimisms of today"[77] – Africa and climate change – issues which ostensibly challenge growth's indefinite promise of progress for all. But Ridley argues that Africa is on the verge of an economic boom that will see the continent prosper, and that climate change will not be catastrophic. In actual fact, mild climate change carries with it both costs and benefits – many of which will outweigh the negatives. He projects that climate change will *reduce* the total population at risk from water shortages, that global food supply will *increase* if temperatures rise by up to 3°C, and ecosystem well-being will *improve* overall, while an extreme climate crisis is extremely unlikely to materialise. Simultaneously, if growth is allowed to continue, the world will be richer, and therefore more able to deal with any problems that arise.

Keeping the growth engine going, however, requires cheap energy – which at present lies in fossil fuels. Ridley argues against what he sees as the extensive, land-greedy and costly nature of many renewable forms of energy, proposing that nuclear is the best low-carbon option. Indeed, he supports the continuation of a fossil-fuel based economy as long as possible, as he believes that it is only non-renewable energy that has made growth "sustainable". This, he acknowledges, appears to be an oxymoron – but he maintains that while in the past renewable forms of energy, such as timber, cropland, pasture, labour (in the form of slaves), water and peat, ran out because they became exhausted by a swelling population, non-renewable energy does not face this limitation as it is "sufficiently abundant to allow expansion of both economic activity and population to the point where they can generate sustainable wealth for all the people of the planet without hitting a ceiling, and can then hand the baton to some other form of energy"[78]. This statement is briefly countered by assessment of peak anxieties over the past centuries about oil, coal and gas, but Ridley dismisses these as-yet disproved concerns, restating that in actual fact "between them they

[73] Ibid, p.28
[74] Ibid, p.353
[75] Ibid, p.281
[76] Ibid
[77] Ibid, p.313
[78] Ibid, p.217

will last decades, perhaps centuries, and people will find alternatives long before they run out"[79].

What are these alternatives? Having heavily criticised many renewable energy technologies on offer today, Ridley instead looks to future "ideas that are barely glints in the engineers' eyes right now"[80] including geo-engineering. The final sentence of the book perhaps underscores the imperative with which he sees his own worldview – "Dare to be an optimist"[81] – implying at the same time the acceptance of risk, deemed minimal, and the assurance of trust, deemed rational, in his assertions.

3.2 Green growth

In 2011 the United Nations Environment Programme's (UNEP's) International Resource Panel published a report on *Decoupling natural resource use and environmental impacts from economic growth*.[82] In it UNEP acknowledges that the attainment of human well-being and social development has come as a result of economic growth, based on the availability and use of natural resources, but that this has come at great cost to the natural environment and thus human security. UNEP present it as fact that the costs are now outweighing the benefits. The report foregrounds the risk of resource depletion and scarcity, due to rising demand and dwindling supply, as a starting point for reassessing the fundamentals of economic growth, making the case that humans need to start achieving more but by using less. This concept of "decoupling" growth from material consumption and environmental impacts is presented as a necessary evolution of economic activity to meet the challenges of global population growth, eradicating poverty and supporting economic development whilst avoiding irreversible damage to ecosystem services on which human welfare depends. Thus economic dematerialisation and increased efficiency is presented as the solution to meeting both sets of goals. Economic growth as a goal twinned with ensuring human well-being is the goal here.

The report provides an overview of global long-term trends in the use of natural resources and their environmental impacts. It focuses on material resources – biomass, fossil fuels, industrial minerals and ores, and construction materials. Energy resources, the carbon cycle, water and land are left out, dealt with by other reports and reviews, both by the IPCC and UNEP's International Resource Panel (IRP) in separate analyses. Between 1900 – 2005, total material resource extraction was found to have increased by a factor of eight while average resource-use per capita – or the "metabolic rate" – doubled.[83] This indicates that while global material resource use rose during the 20th century at twice the rate of population growth, it did not grow as rapidly as the total world economy (global GDP increased by a factor of 23[84]), thus a "spontaneous"[85] process of resource decoupling is apparent despite declining resource prices. However, this has also come as a result of the shifting of

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[79] Ibid, p.238
[80] Ibid, p.346
[81] Ibid, p.359
[82] UNEP, *Decoupling natural resource use and environmental impacts from economic growth*, A Report of the Working Group on Decoupling to the International Resource Panel, M. Fischer-Kowalski, M. Swilling, E. U. von Weizsäcker, Y. Ren, Y. Moriguchi, W. Crane, F. Krausmann, N. Eisenmenger, S. Giljum, P. Hennicke, P. Romero Lankao, A. Siriban Manalang, S. Sewerin (Switzerland: UNEP, 2011) <http://www.unep.org/resourcepanel/decoupling/files/pdf/decoupling_report_english.pdf> [accessed Feb 2012]
[83] Ibid, p.10
[84] Ibid, p.14
[85] Ibid, p.11

environmental and material burden to developing countries, with the metabolic rate very different among countries and among regions. Generally speaking among highly industrialised countries the metabolic rate has stabilised, while in many other parts of the world the rate is still rising.

The report concludes by examining assumptions about economic growth and the possibility of rethinking growth indicators and measurements, suggesting a 'Decoupling Index' as one future measure of progress. A new focus on "eco-innovation"[86] is called for, particularly for resource productivity, in order to meet the challenge of decoupling, while the role of cities is scoped out as having the greatest potential in terms of reducing the global metabolic rate in an increasingly urbanised world. The report ends by affirming that decoupling might offer the means by which the world could progress towards more sustainable development.

In 2011, the OECD published a series of papers in response to the Green Growth Declaration signed by 34 ministers in June 2009 that called for the development of a strategy for green growth. The aim of the resultant *Towards Green Growth*[87] framework is to kick-start the process of mainstreaming green growth strategies into national government policies and begin the work of monitoring progress. The report agrees that new thinking and revised strategies on growth and progress indicators are required if we are to avoid crossing "critical local, regional and global environmental thresholds"[88]. It recognises that a return to 'business-as-usual' after the current economic crisis would incur huge risks, costs and constraints for long-term economic growth and development in the form of environmental resource scarcity, bottlenecks and negative impacts. A move towards 'green growth', on the other hand, would foster economic development while ensuring natural assets "continue to provide the resources and environmental services on which our well-being relies"[89]. Achieving this will require productivity gains, innovation, the creation of new markets, increased investor confidence and macroeconomic and resource-price stability which will give rise to new green jobs. The green economy will be more resilient, more able to deal with resource scarcity shocks, and more adaptable, better able to cope with natural resource imbalances.

Creating this green economy will not be easy. It will require more efficient resource use and management practices as well as new economic and environmental policies that incorporate a longer time horizon. These would include two sets of policies: the first, focusing on establishing framework conditions that mutually reinforce economic growth and natural capital conservation. For example, fiscal and regulatory mechanisms, such as tax and competition policy, that encourage the efficient allocation of resources and innovation policies that place a premium on the inventiveness needed to ensure natural resource decoupling. The second set would include policies aimed at incentivising efficient use of natural resources and making pollution more costly, particularly pricing environmental externalities correctly. Bringing these policies to bear will require global collaboration and the development of appropriate national and international institutional capacity, a significant challenge. Furthermore, implementing these policies will not always prove popular, due to potential negative distributional effects in the short-term, for example of removing fossil fuel subsidies. Thus making these policies publicly acceptable will be

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[86] Ibid, p.36
[87] OECD, *Towards Green Growth*, (Paris: OECD Publishing, 2010) <http://www.oecd.org/document/10/0,3746,en_2649_37465_47983690_1_1_1_37465,00.html> [Accessed Feb 2012]
[88] Ibid, p.10
[89] Ibid, p.9

necessary to ensure their success, and targeted compensatory measures may be needed in order to achieve this.

The McKinsey Global Institute, after analysing global resource trends and risks calls for nothing short of a "resource revolution" to meet the scale of the challenge of rising demand, resource price inflation and volatility, and increasing supply vulnerabilities. Their report, *Resource Revolution: Meeting the world's energy, materials, food and water needs*[90] (2011), recognises that economic growth over the past century has been underpinned by progressively cheaper resources. Rising demand was met by expanding supply and productivity increases. Today, however, demand for resources is surging and resource price rises over the past ten years have wiped out all the price declines that occurred in the 20th century. McKinsey thus warn that we may have entered an "era of sustained high resource prices and increased economic, social and environmental risk"[91] with negative consequences for economic growth, human welfare, public finances and the environment. While concerns over limits to growth have been met by market adaptation and innovation, the current scale of the challenge, McKinsey states, should "not be underestimated"[92].

McKinsey say it is "unprecedented"[93]. In the next 20 years projections anticipate 3 billion more middle class consumers, up from 1.8 billion today, at a time when finding new supply sources and extracting them is becoming more expensive and technically difficult.[94] Adding to this is the fact that our resource vulnerabilities are increasingly connected, heightening the risk that scarcity and price volatility could spread across the resource web, while ecological damage is only exacerbating those risks further. The final challenge, meeting the basic needs of the world's poorest people, adds a further dimension to the resource conundrum. Thus McKinsey's research points to the need for a "step change in the productivity of how resources are extracted, converted and used" in order to "head off potential resource constraints over the next 20 years"[95]. It leaves open the question as to whether the private sector and governments are able to implement the recommendations quickly enough to avoid the economic, social and environmental repercussions of not doing so in the face of current trends and future projections.

The report identifies three possible scenarios for the global economy. It is important to note that McKinsey do not incorporate rising prices in response to increased demand in their scenarios, which in turn could scale back demand. The first scenario is the 'supply expansion case'. In this scenario, no productivity growth is assumed beyond current policy and economic projections in business-as-usual, placing the burden of demand on increasing supply. Supply expansion would need to occur at a historically unprecedented rate – almost triple the rate at which it expanded over the past two decades[96]. This would be costly in the areas of water and land both financially and environmentally. Innovation is expected to play a central role in generating supply, especially in the energy sector, where unconventional sources come online. However, capital infrastructure and geopolitical risks would also be

[90] McKinsey Global Institute, *Resource Revolution: Meeting the world's energy, materials, food and water needs*, R. Dobbs, J. Oppenheim, F. Thompson, M. Brinkman, M. Zornes (McKinsey Global Institute, 2010). Available at <http://www.mckinsey.com/Features/Resource_revolution> [Accessed Feb 2012]
[91] Ibid, p.1
[92] Ibid, p.2
[93] Ibid, p.32
[94] Ibid, p.xi
[95] Ibid, p.2
[96] Ibid, p.61

likely in this scenario, particularly in the face of global capital scarcity, while increasing environmental harm would be the likely fallout.

The second scenario offered is the 'productivity response', which incorporates both significant productivity improvements as well as remaining supply expansion. This scenario would meet nearly 30% of resource demand by 2030 and deliver savings of between $2.9 – 3.7 trillion to society.[97] It is anticipated these gains would mostly offset increases in demand, for example, 80% of the growth of demand for energy, 60% for water, and 25% for steel[98]. Just 15 opportunity areas could account for 75% of these resource productivity gains.[99] However, the report warns, capturing these opportunities will not be easy as only 20% are readily achievable, with 40% facing many barriers to their realisation.[100] This scenario would require large capital investment to the tune of $100 billion more per year than the supply expansion case – or $1.2 trillion per annum above historical expenditure, leading to increased institutional and managerial challenges.[101]

These two scenarios – the 'productivity response scenario' and the 'supply expansion scenario' – would not be enough, however, to limit global warming to no more than 2°C – or alleviate resource poverty. The report thus presents a third scenario – the 'climate response case'. This scenario would see an increased focus on shifting from high-carbon to low-carbon energy, on reforestation and land restoration initiatives, on improved timberland management, and on efforts to increase pastureland productivity. It would also see the scaling up of investment in carbon capture and storage technology and second generation biofuels. This scenario would require an additional $260 – 370 billion a year in investment over the next 20 years, with an additional $50 billion for ensuring universal energy access.[102]

Adding to its recommendations, McKinsey outline a number of institutional and regulatory responses that would aid the transition towards the "resource revolution". These include: a shift in mindsets towards an integrated approach to resource management across ministries and nations; strengthening market signals (ensuring resource price certainty, removing inefficient subsidies, pricing externalities, and providing stable policy regimes); correcting non-price market failures (related to property rights, agency issues, setting standards, and enhancing access to capital); and bolstering society's long-term resilience (raising awareness, developing safety nets, and educating consumers and businesses towards sustainable behaviour). Finally, the private sector is called upon to increase their strategic and operational focus on resource productivity, simultaneously improving their competitive advantage in a resource-constrained world.

In 2008 Shell developed two scenarios to demonstrate the possible responses to meeting the future energy challenge in particular.[103] In 'Scramble', policymakers do not invest in enhancing energy efficiency until supplies are tight while greenhouse gas emissions are not addressed until there are major climate shocks. In 'Blueprint', local actions steadily begin to address the tripartite challenges of ensuring continued economic growth, delivering energy

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[97] Ibid, p.2
[98] Ibid
[99] Ibid, pp.2 -3
[100] Ibid, p.3
[101] Ibid, p.10
[102] Ibid, p.15
[103] Shell, *Shell Energy Scenarios to 2050* (The Hague, The Netherlands: Shell International BV, 2008) <http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/shell_energy_scenarios_2050/#subtitle_2> [Accessed Feb 2012]

security and mitigating environmental pollution. Carbon is priced accordingly stimulating development of clean energy technologies and energy efficiency measures, thus bringing down emissions levels. In 2011, Shell published *Signals and Signposts*[104], which updated their thinking on these two scenarios to take into account the effects of the global financial and economic crisis and examined the evidence for each scenario's likelihood.

Shell finds that signals are mixed as to whether Scramble or Blueprint is emerging as the winner. For example, in Scramble, bilateral state-sponsored energy deals are increasingly common while the use of cheap coal is on the rise. However, in Blueprint, public-private partnerships and international collaboration, as between central banks during the financial crisis, are more apparent. As Shell see it, the world faces a choice between knee-jerk reaction later or smart planning now, particularly as supply, demand and environmental stresses are predicted to "swell and spread"[105] in the coming years. They identify climate change as the main cause of concern for the energy sector, but stress that an integrated, ecosystems approach, like that provided by the *Planetary Boundaries* research of the Stockholm Resilience Centre (discussed in the following chapter), is required to managing environmental policy if we are to avoid stressing other ecological boundaries through our actions. Shell believes limits are encroaching and thus it is decision time. The choice between Scramble and Blueprint is a choice between immediate policy preparation or delayed, costly action at the breaking point. Shell, breaking with their own company policy of neutrality, firmly promote early adoption of the 'Blueprint' scenario as providing the "best hope for a sustainable future for all of us"[106]. However, it warns that even achieving the transformation put forward by 'Blueprint', atmospheric concentrations of CO_2 are higher than considered responsible by many climate scientists, thus it might even be necessary for us to move faster and harder than this.

Shell concludes that at present we are moving slower than the pace that Blueprints itself aspires to. Thus moving any faster would be a significant feat, since economic volatility and cyclicality "threaten to depress the pace of change further"[107]. We are currently on a pathway to overshooting 'safe' emissions levels – closer to Scramble than Blueprint. But Shell is confident in the market's ability to deliver efficiency and productive change, given that the right policy and regulatory frameworks are put in place. Thus the key to initiating brisk transformation lies in unblocking the market's ability to deliver the right sort of growth quickly. Shell is not advocating radical change, but is in favour of 'greening' capitalism, or "reshaping the capitalist model"[108], but perhaps with a greater role for the state and industrial policy than has previously been the case. They say: "It is difficult…to envisage the emergence of an alternative to capitalism. All approaches that we have exist within a broad capitalist framework, with variants that are either more market-centric or more state-focused."[109]

Depicting a world currently closer to 'Scramble', the International Energy Agency (IEA) outline the current status of energy demand and supply in their 2011 World Energy

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[104] Shell, *Shell Energy Scenarios Signals& Signposts* (The Hague, The Netherlands: Shell International BV, 2011) <http://www.shell.com/home/content/aboutshell/our_strategy/shell_global_scenarios/signals_signposts/> [Accessed Feb 2012]

[105] Ibid p.10

[106] Ibid, p.12

[107] Ibid, p.69

[108] Ibid, p.36

[109] Ibid, p.35

Outlook.[110] They find that CO_2 emissions are at an all time high, global energy intensity worsened for the second straight year and there is little sign of change in direction of energy trends. Added to this are increasing concerns about energy security, due to the Fukushima disaster and events in the Middle East, as well as public debt, shifting attention away from climate change mitigation efforts and energy policy intervention. The IEA analysis presents three scenarios examining possible future energy pathways – the 'Current Policies Scenario', which assumes no new policies as of mid-2011; the 'New Policies Scenario', in which recent government commitments are assumed to be implemented in a cautious manner; and the '450 scenario', which works back from the goal of limiting global warming to below 2°C. The broad differences between these scenarios underline the "central role of government to define the objectives and implement the policies necessary to shape our energy future"[111]. Of most interest here are the 'New Policies Scenario' and '450 scenario' in terms of possible responses to limits to growth.

In the IEA's central 'New Policies Scenario', demand for energy grows by one third by 2035 parallel to a 3.5% annual average economic growth rate.[112] Non-OECD countries increasingly establish the rules of play in energy markets, accounting for 70% of the increase of economic output and 90% of energy demand growth.[113] In this scenario fossil fuel dominance declines, with natural gas the only fossil fuel increasing its energy share in the mix. Global coal use rises for the next ten years, but then levels off at 25% above 2009 figures.[114] Energy efficiency dramatically improves – by twice the rate experienced over the past 25 years.[115] However, despite these efforts, policies implemented under the 'New Policies Scenario' place the world on a trajectory that will result in warming of more than 3.5°C. But the IEA say that without these policies, the world would be more likely to reach 6°C of warming.

In '450', four-fifths of the total energy-related CO_2 emissions allowed by 2035 are already "locked-in" by existing capital stock.[116] The IEA warn that if tougher policy is not implemented by 2017, the "energy-related infrastructure then in place will generate all the CO_2 emissions allowed in the 450 Scenario up to 2035, leaving no room for additional power plants, factories and other infrastructure unless they are zero-carbon, which would be extremely costly"[117]. Delaying action is more costly in the long-run. Energy efficiency measures are not enough in this scenario, as efforts to cut down the amount of energy we use are also needed. To achieve the goals of the 450 scenario, global coal consumption must peak well before 2020 and then decline. Currently China consumes over half of world coal, which has met almost half the increase of energy demand over the last decade.[118] Achieving both energy and climate security is thus a challenge and the future of coal plays a central role. The report also warns that "second thoughts on nuclear", particularly as a response to the Fukushima disaster, would have "far reaching consequences"[119]. Since we have reached the "end of cheap oil"[120], nuclear needs to be part of the energy mix, while both natural gas and renewables will need to increase their contributory share.

[110] IEA, *World Energy Outlook: Executive Summary* (Paris: IEA, 2011)
[111] Ibid, p.1
[112] Ibid
[113] Ibid
[114] Ibid, p.5
[115] Ibid, p.2
[116] Ibid
[117] Ibid
[118] Ibid, p.5
[119] Ibid
[120] Ibid, p.3

3.3 The end of growth

In 2005, the research team behind the original *Limits to Growth* report published a *30-Year Update*[121] which restated the 1972 argument providing the latest supporting evidence and data. The aim of the book was to re-stress that humanity is in "overshoot"[122] mode – it is overextending the capacity of the biosphere to support and provide for human needs and wants – and thereby to encourage the development and implementation of wise policy that would reduce the damage and bring humanity back from the brink of potential collapse. The book begins with a closer examination of the concept of "overshoot" – the central tenet of the Limits to Growth thesis. Overshoot has three consistent causes: 1) rapid change met by 2) limits or barriers to that change, followed by 3) "errors or delays in perceiving the limits and controlling the change"[123]. The consequences of overshoot can be twofold: either a "crash" or a "deliberate turn around"[124].

The authors of the book predict that unless a "profound correction", indeed a "revolution as profound as the agricultural and industrial revolutions"[125], occurs soon, then the "crash" scenario is certain. This is based on their analysis of scientific and economic theories about the global system and world resource and environment data, which they have then integrated into a computer model, 'World3', to generate various scenario implications. They also acknowledge that their "worldview"[126] – their way of looking at the world – has inevitably shaped their analysis too. This worldview is that of a "systems perspective"[127], which sees the world in terms of the interconnections, patterns and interactions between events, issues, behaviours and dynamics.

The book is structured around assessment of the three causes of overshoot. It takes off by looking at the driving factors behind rapid global change, particularly exponential growth of the human population and of the economy, two trends that have shown to be the dominant behavioural pattern of the world socioeconomic system for over 200 years. This is a result of both the "fantasy of an infinite globe"[128] and the cultural myth that the "blind pursuit of physical growth"[129] is the only pathway towards ever-increasing human welfare, indeed the only mechanism by which we solve our collective problems, even those caused by growth itself. The authors take some time to explain the oft-misunderstood dynamics of 'exponential growth', the driving force of overshoot. The rapid pace of change can be surprising, since huge numbers can be produced very quickly through the process of redoubling and redoubling again, leading to situations where "insignificance" can rapidly shift to "overload"[130]. Thus, the book argues, exponential physical growth in a finite world ultimately makes problems worse in the long-run. At the same time, believing that another fourteen-fold increase of world industrial output (the scale of change since 1930) would lead to the eradication of poverty, is fundamentally flawed since the global system does not have the correct feedback systems to solve this issue, set as it is on a "success to the

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[121] Donella Meadows, Jorgen Randers and Dennis Meadows, *Limits to Growth: The 30-Year Update*, (London: Earthscan, 2010)
[122] Ibid, p.xii
[123] Ibid, p.5
[124] Ibid, p.3
[125] Ibid, p.12
[126] Ibid, p.4
[127] Ibid
[128] Ibid, p.12
[129] Ibid
[130] Ibid, p.22

successful"[131] mode of operation. Thus "running the same system harder or faster will not change the pattern as long as the structure is not revised"[132]. Continued growth in the current model will only add to the growing rich / poor divide, not solve it.

More profoundly, continuous growth is just not an option. This is because of limits – limits to the "continuous flow of energy and materials needed to keep people, cars, houses, and factories functioning" – or limits to "throughput"[133]. Crucial facets of the biophysical support system on which our economy is based are either degrading or depleting. A range of sources – material resources – and sinks – pollutant processors – are examined against a set of core questions: Are renewables being used faster than they regenerate? How quickly are high quality stocks of non-renewable resources being used? And what is the course of the true costs in energy and capital required to provide them? Finally, are pollutants and wastes being rendered harmless at sufficient rates or are they accumulating? Both sources and sinks are found to be stressed and already causing barriers to indefinite growth in the form of rising costs, increasing environmental damage, and growing mortality rates. The report concludes that eventually, these costs will be so high that it will no longer be possible to sustain industrial growth, and the economy will begin to contract in a negative feedback loop, i.e. growth will cease, and fall into decline. At the same time, with current rates of resource consumption and waste production at unsustainable levels, many sources and sinks will reach their peaks and start to decline over the remainder of this century.

The authors suggest, like UNEP, that 'decoupling' offers one way of dealing with this problem, since rising human welfare and increasing material throughput are not necessarily mutually dependent. It is theoretically possible to provide a good standard of living and reduce our ecological footprint. However, the changes and political choices are not occurring, at least not fast enough, to turn this theory into practice. Equally, technological innovation and market efficiency in the absence of respect for limits are not in themselves enough to avoid overshoot. In a world driving only towards exponential expansion, such mechanisms will only cause further problems, since they are only the tools that "serve the goals, the ethics, and the time horizons of society as a whole"[134]. If the goals are wrong, the technology and the markets will be wrong and they will continue to produce wrong results. A second cause for doubt in the ability of technology or markets to solve all is the fact that as limits approach the costs of resources rise exponentially. This undermines the claim that further growth will enable societies to afford greater pollution abatement, since the cost curve reaches a point where further abatement becomes unaffordable and gains in welfare cease or begin to decline. The final cause for doubt is that information distortions and delays that exist in the market and technology responses can cause misrepresentation of biophysical realities, pushing us closer to overshoot rather than reigning us back. We need to think bigger than political, technical and market-based fixes – we need the "next revolution: sustainability"[135], which means systemic innovation and change.

Thus in final chapters, the report explores the parameters of 'real' sustainability, assuming that the world beings to adopt "two definitions of *enough*, one having to do with material consumption, the other with family size"[136]. The authors suggest, as with the Shell scenarios, we face a stark decision between a "smooth transition" or "abrupt collapse" in which we "let

[131] Ibid, p.44
[132] Ibid, p.43
[133] Ibid, p.8
[134] Ibid, p.223
[135] Ibid, p.269
[136] Ibid, p.11

nature force the decision"[137]. The authors present the case that physical growth will ultimately cease completely – whether we like it or not. "The only questions are when and by what means."[138]

Richard Heinberg makes the same assertion, but perhaps more immediately explicitly, in his book titled *The End of Growth* (2011)[139]. On the very first page he announces that "economic growth as we know it is over and done with"[140]. This is because the world is colliding with "fundamental barriers to ongoing economic expansion" and thus from now on only "relative growth is possible: the global economy is playing a zero-sum game, with an ever-shrinking pot to be divided among the winners"[141]. This is not a temporary lull, but a permanent, terminal end to growth. For Heinberg there are three fundamental causes: 1) the depletion of natural resources; 2) related negative environmental impacts and; 3) financial disruptions due to the inability of our existing monetary, banking, and investment systems to adjust to 1 and 2 while simultaneously servicing growing public and private debt accumulated over the past couple of decades.

This latter point is perhaps where Heinberg adds most to the *Limits to Growth* perspective, analysing in more detail the financial aspects and implications of the end of growth. He begins by providing a quick history of economics and the development of our global economy, assessing the financial limits to growth. He asks the question "Why is growth so important?"[142]. He explains the linkages between growth, employment, investment and consumer lifestyles, arguing that our monetary and financial systems are so designed that they *require* growth to sustain themselves, based on an unsustainable structure of credit and debt, as discussed in chapter 2. This mechanism means that our economy has no 'stable' state – only one of growth or contraction, boom or bust. This debt has grown so large that it cannot be repaid and represents claims on labour and resources that do not exist. While debt has grown 500% since 1980, natural resource stocks have declined and depleted.[143] But our money supply is based on debt; debt is required in order to bring money into existence. Future growth has thus become necessary simply to ensure that the debt to revenue ratio is kept proportional, that debt servicing continues and thus that further borrowing is possible. This is only viable, Heinberg points out, if the economy has infinite potential to grow. The result is economic collapse – as in the financial crisis of 2007/8.

This is because of factors external to the financial and monetary systems blocking efforts to restart growth. Heinberg argues that there is an intrinsic assumption that growth *will* resume, it is only a matter of "when"[144]. However, these external factors, whose impacts are worsening, mean that this assumption is flawed. These include scarcity of energy resources, minerals, food and water as well as increasing risks to human and ecological health of industrial accidents and environmental disasters, including climate change. Both groups of factors involve ever-increasing costs related to recovery and avoidance, which in a money-constrained world will translate into ever-greater demands on government and private spending. At the same time these factors are heavily interlinked. Since growth has become

[137] Ibid, p.13
[138] Ibid, p.48
[139] Richard Heinberg, *The End of Growth: Adapting to Our New Economic Reality* (East Sussex: Clairview Books, 2011)
[140] Ibid, p.1
[141] Ibid, p.2
[142] Ibid, p.6
[143] Ibid p.51
[144] Ibid, p.105

dependent on fossil fuel consumption, it is thus particularly the coming end to cheap and abundant fossil fuels that is shaking "our assumptions about continued expansion... to the core"[145].

The peaking of energy resources, such as oil, coal and gas, can be seen in the rising costs of production, supply bottlenecks, and declining amounts of energy returned on energy invested (EROEI). As a result, Heinberg states that "the world has reached immediate, non-negotiable energy limits to growth"[146]. Dwindling freshwater supplies will further limit economic growth through its impacts on human mortality, human well-being (from meeting basic needs to causing conflict), agricultural output, mining and manufacturing output, and energy production reliant on water. As water becomes scarcer more energy will be required to obtain it, but as energy resources become scarcer, more water will be needed to obtain energy (e.g. in intensive extraction processes). Food production, in turn challenged by water scarcity, is also facing the problems of soil erosion, declining soil fertility, reduction of arable land availability, declining seed diversity, increasing input requirements, and increasing fossil fuel input costs. But as the energy required to maintain the food system becomes more costly, food is increasingly being used to make energy in the form of biomass. Together with rising demand and climate instability, Heinberg predicts a "global world food crisis sometime in the next two or three decades"[147].

Further compounding problems are the reliance of our food, water and energy systems on the financial systems of credit and debt – a prolonged credit crisis will be devastating for the necessary investment in more costly inputs, infrastructure and research into alternatives. Metal and mineral depletion, essential for energy production and manufacturing (including of agricultural machinery, infrastructure and hi-tech electronics), is also concerning. In short, we are reaching "Peak Everything"[148], including in the form of climate change, environmental disasters, pollution and general ecological decline. Dealing with this will be extremely expensive. Heinberg warns, "Until now the dynamism of growth has enabled us to stay ahead of accumulating environmental costs. As growth ends, the environmental bills for our last two centuries of manic expansion may come due just as our bank account empties"[149]. Rather than being richer, and thus better able to deal with our future problems as Ridley predicts, Heinberg presents the opposite case – that we face limits to the amount of energy and materials we can devote to addressing environmental problems because growth will cease.

Simultaneously, while technical innovation will likely continue out of necessity, this time our inventiveness will be constrained by a world of expensive, declining energy and materials, rather than supported, as in the past, by access to cheap, seemingly unlimited resources. This time, the market, substitution, and efficiency will not keep growth going, particularly in the "blind disregard of limits"[150]. Creativity is needed, but in dealing with these limits, not pushing through them. The last two chapters of the book are devoted to looking at how one might redefine progress, what might happen after growth, including assessment of 'steady-state economics', and the possible responses and preparations citizens and governments alike could be making to "weather the approaching storms"[151]. The end of growth is a

[145] Ibid, p.7
[146] Ibid, p.118
[147] Ibid, p.137
[148] Ibid, p.143
[149] Ibid, p.153
[150] Ibid, p.229
[151] Ibid, p.270

historic moment – the end of an era, not necessarily heralding a new revolution, as in the vision put forward in *Limits to Growth*, but signalling the beginning of the transition, or adaptation, to something slightly more subdued – a "no-growth economy" or a "new normal"[152]. Once again, the choice is either a "managed contraction"[153] or a sudden, distressing bid for survival.

Tim Jackson, in his book *Prosperity Without Growth: Economics for a Finite Planet* (2009)[154] realises that our instinctual reaction to this will be disbelief and rejection. This is because, "Questioning growth is deemed to be the act of lunatics, idealists and revolutionaries"[155], so entrenched is it in our globalised cultural mythology. However, "question it we must" as "no subsystem [the economy] of a finite system [ecology] can grow indefinitely, in physical terms"[156]. Jackson emphasises the disparity with which growth has delivered its benefits to the world – one fifth of the world's population earns just 2% of global income, while even within so-called 'advanced' nations, inequality is also higher than it was 20 years ago[157]. Justice is one concern, but social security and stability is another. Furthermore, even without limits, this points to questioning whether, beyond a certain point, growth really does add to human well-being, or begin to detract from it. In this book Jackson argues that "prosperity" is the "ability to flourish as human beings – within the ecological limits of our finite planet" and that therefore, "the challenge for our society is to create the conditions under which this is possible".[158]

Jackson takes as his starting point, like Heinberg, the economic meltdown of 2007/8, dubbing it the culmination of the "age of irresponsibility"[159]. The pursuit of consumption growth has taken into account neither our financial nor ecological debts. Protecting growth has been our main standpoint – at almost any cost, from financial instability to ecological liability – in the belief that this would deliver long-term security and prevent collapse. Responses, therefore, to the economic crisis that attempt to bring us back to the status quo are "deeply misguided and doomed to failure"[160] as this is not sustainable in any terms. Indeed "prosperity today means nothing if it undermines the conditions on which prosperity tomorrow depends"[161].

At present, however, our definition of prosperity is such that growth is deemed a necessary condition for its achievement. Jackson seeks to prove his argument for "prosperity without growth" by undermining the claims made by supporters of continued growth. He thus spends some time assessing whether this assumption has any merit. Perhaps, in order to flourish, have access to basic needs, and maintain economic and social stability we need growing monetary wealth. Firstly, Jackson finds that our attachment to material consumption is borne out of our desire for social meaning related to our sense of belonging, identity and social status. Thus if societies were more equal we could perhaps extricate ourselves from the trap of "positional competition"[162], whereby individuals' well-being is

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[152] Ibid, p.21
[153] Ibid, p.231
[154] Tim Jackson, *Prosperity Without Growth: Economics for a Finite Planet* (London: Earthscan, 2011 ed.)
[155] Ibid, p.14
[156] Ibid
[157] Ibid, p.5
[158] Ibid, p.16
[159] Ibid, p.17
[160] Ibid, p.33
[161] Ibid
[162] Ibid, p.53

founded on relative wealth, and find less materialistic ways for people to participate in society. Monetary wealth is not in itself the goal – suggesting there may be other strategies for meeting intrinsic psychological needs that are pre-requisites for 'flourishing'.

Secondly, Jackson assesses the relationship between income and basic entitlements. While it is true that the poorest countries suffer the greatest levels of deprivations in life expectancy, infant mortality and educational participation, as income goes above $15,000 per capita, the "returns to growth diminish substantially"[163]. The relationships are not hard and fast, however, at best they are ambivalent. Thus growth is no guarantee of improved prosperity in this sense. Finally, Jackson looks at the correlation between income growth and economic stability. In the face of recessions and economic crises, people lose jobs; livelihoods suffer; in the worst cases, humanitarian disasters ensue. This leads to the "dilemma of growth"[164]: growth is unsustainable due to ecological limits, but "de-growth"[165] is also unsustainable under present conditions because modern economies need growth in order to be stable. Failure to tackle this dilemma is "the single biggest threat to sustainability that we face"[166]. What are the solutions?

Jackson highlights, as we have seen, that the concept of 'decoupling' is usually suggested as a conventional response. However, in assessing the evidence for whether this approach has been, or will be, successful, Jackson finds that it is "far from convincing"[167]. Although it is vital for us to do, the claim that it will achieve ecological targets is a further "myth"[168]. This is because, in relative terms, whilst there has been *some* progress towards decoupling in terms of ecological intensity per unit of economic output, (although this is wavering), in absolute terms – for the economy overall – decoupling is just not happening. For example, despite relative declining energy and carbon intensities, carbon dioxide emissions have increased by 80% since 1970[169]. This is also the story of material throughputs, with resource efficiency actually worsening, for example, across a number of non-fuel minerals[170]. Jackson thus questions how much decoupling is actually achievable, particularly since demand is surging, in all likelihood cancelling out any efficiency gains. Jackson highlights that if we were to grant citizens around the world access to comparable incomes to those enjoyed within the EU, the economy would need to grow six times between now and 2050.[171] To achieve the IPCC 450 ppm target alongside this, carbon intensity of output would need to decline by 9% a year for the next 40 years, with average carbon intensity bottoming-out at 55 times lower than today.[172] Decoupling is not a strategy that on its own will deliver the kind of economy that will tackle such challenges.

Next on the list of solutions, Jackson assesses the 'green growth' model, specifically the 2008 call for a global 'Green New Deal', finding that, ultimately, this path is equally unsustainable since it seeks to return the economy to a "condition of continuing consumption growth"[173]. Thus "it is difficult to escape the conclusion that something more is needed"[174]. This is

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[163] Ibid, p.59
[164] Ibid, p.65
[165] Ibid
[166] Ibid
[167] Ibid, p.68
[168] Ibid
[169] Ibid, p.71
[170] Ibid, p.75
[171] Ibid, p.80
[172] Ibid, p.80 - 81
[173] Ibid, p.104
[174] Ibid

because achieving absolute decoupling is not achievable in this framework, while any sort of consumption growth pushes us "relentlessly towards ever more unsustainable resource throughput"[175]. Thus Jackson proposes a different kind of economic structure altogether – an "ecological macroeconomics"[176]. This economy is one in which "stability no longer relies on ever-increasing consumption growth… economic activity remains within ecological scale… our capabilities to flourish – within ecological limits – becomes the guiding principles for design and the key criterion for success"[177]. Parallel to this, we must address the "social logic of consumerism"[178], to deliver a more sustainable, equal, happy, and less anxious society. The final chapters are dedicated to exploring the requirements for social change towards prosperity without growth, including establishing the ecological bounds of human activity, fixing the "illiterate economics of relentless growth"[179], and, finally, transforming the social logic of consumerism.

3.4 Beyond the limits

The Stockholm University's Resilience Centre report *Planetary Boundaries: Exploring the Safe Operating Space for Humanity*[180] (2009) identified nine planetary boundaries within which humanity can safely operate, suggesting quantification for seven of these based on current scientific understanding. These seven are climate change; ocean acidification; stratospheric ozone; the biogeochemical nitrogen and phosphorus cycle; global freshwater use; land system change; and the rate at which biological diversity is lost. The two boundaries for which no set quantified limit has been defined are for chemical pollution and atmospheric aerosol loading, due to lack of data. The authors believe it is necessary to set such boundaries, despite huge uncertainties, as "Transgressing one or more…may be deleterious or even catastrophic due to the risk of crossing thresholds that will trigger non-linear, abrupt environmental change within continental- to planetary-scale systems"[181]. However, they estimate that humanity has already crossed three of these thresholds – climate change, rate of biodiversity loss, and changes to the nitrogen cycle. What is more, these thresholds are interdependent; "transgressing one may both shift the position of other boundaries or cause them to be transgressed"[182].

The report is based on the observation that human activities are placing unprecedented strain on the Earth's systems, largely through exponential growth behaviour. The result is a "profound dilemma" since "the predominant paradigm of social and economic development remains largely oblivious to the risk of human-induced environmental disasters at continental and planetary scales"[183]. The boundaries are necessary to establish a "safe operating space"[184] for humanity. The authors distinguish between 'thresholds' and

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[175] Ibid, p.118-119
[176] Ibid, p.121
[177] Ibid, p.122
[178] Ibid, p.143
[179] Ibid, p.204
[180] J. Rockström, W. Steffen, K. Noone, Å. Persson, F. S. Chapin, III, E. Lambin, T. M. Lenton, M. Scheffer, C. Folke, H. Schellnhuber, B. Nykvist, C. A. De Wit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P. K. Snyder, R. Costanza, U. Svedin, M. Falkenmark, L. Karlberg, R. W. Corell, V. J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, and J. Foley , 'Planetary boundaries: exploring the safe operating space for humanity', *Ecology and Society*, 14 (2): 32 (2009) <http://www.ecologyandsociety.org/vol14/iss2/art32/> [Accessed Feb 2012]
[181] Ibid, p.1
[182] Ibid
[183] Ibid, p.2
[184] Ibid, p.1

'boundaries'. The former are "non-linear transitions in the functioning of coupled human–environmental systems"[185], defined by a position on one or more control variables. Boundaries, on the other hand, are "human determined values of the control variable set at a 'safe' distance from a dangerous level (for processes without known thresholds at the continental to global scales) or from its global threshold"[186]. The setting of boundaries requires normative judgement of how societies choose to deal with risk and uncertainty.

The purpose of the report is to set a "planetary boundaries framework"[187] within which governance practices can find sustainable development pathways. One key problem is that there remain many "disturbing"[188] gaps in our knowledge regarding impacts of transgressing boundaries and feedback mechanisms. What is clear, however, is that transgressing one boundary may "seriously threaten the ability to stay within safe levels for other boundaries. This means that no boundary can be transgressed for long periods without jeopardising the safe operating space for humanity"[189]. In addition, crossing boundaries for longer periods of time may result in the inability of the system to return to safe levels at all. The problem is we do not know. Following the precautionary principle, humanity must become an "active steward"[190] of all boundaries now, including those not yet identified, to avoid catastrophe.

Although there are great uncertainties as to the impacts of transgressing planetary boundaries, as the Stockholm academics state, a number of reports have attempted to look in detail at the potential ramifications of continued growth, as far as we know. The risks of extreme climate change are perhaps the leading concern.

In their *Unburnable Carbon*[191] report (2011), the Carbon Tracker Initiative take as their starting point the remaining carbon budget for the next 40 years up to 2050. This is based on research by the Potsdam Institute, which calculates that to reduce the chance of exceeding 2°C warming to 20%, the global carbon budget for 2000 – 2050 is 886 GtCO_2.[192] Subtracting emissions already released between 2000 – 2010, a 565 GtCO2 budget now remains.[193] That is to say, this is the theoretically 'burnable' carbon if we are to stay within the 2°C threshold. This is two-thirds of the total budget, meaning we have already used one-third in the space of a decade. The *Unburnable Carbon* report examines the financial implications of this finding, assessing fossil fuel reserves held by publicly listed companies and the way they are valued by markets. Since, currently, fossil fuel reserves are treated as assets, the implication of a policy change resulting in not being able to burn all currently listed reserves for investors and corporations alike are significant. What were once assets would become stranded on the way to a low-carbon economy, leading to the world's largest listed coal, oil and gas companies and their investors being subject to impairment. London in particular stands open to risk as a global financial centre, since the CO_2 potential of its listed reserves account for 18.7% of the total carbon budget – 100 times the carbon footprint of the UK's own physical carbon reserves.[194]

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[185] Ibid, p.2
[186] Ibid, p.3
[187] Ibid, p.21
[188] Ibid
[189] Ibid
[190] Ibid
[191] Carbon Tracker Initiative, *Unburnable Carbon: Are the world's financial markets carrying a carbon bubble?* (London: Carbon Tracker Initiative, (2011) <http://www.carbontracker.org/wp-content/uploads/downloads/2011/07/Unburnable-Carbon-Full-rev2.pdf> [Accessed Feb 2012]
[192] Ibid, p.2
[193] Ibid
[194] Ibid

The Potsdam Institute calculated total potential emissions from burning the world's current proven reserves of oil, coal, and gas. They found that the total CO_2 potential comes to 2795 $GtCO_2$; 65% from coal, 22% from oil; and 13% from gas.[195] This is five times the carbon budget for the next 40 years, meaning only 20% of this is considered 'burnable' to avoid dangerous climate change.[196] According to IEA projections, unburnable carbon will be reached in just 16 years if energy consumption grows in the manner of business-as-usual.[197] The implications of continuing to treat these reserves as assets, and of using them, are clear. Technology options, such as Carbon Capture & Storage (CCS), could be a means of creating more space in the budget. However, the Carbon Tracker Initiative find that although viable CCS may provide *some* extra carbon budget in the medium-term, this could only be applied to coal and gas, leaving the oil-based transport system unmitigated, while overall, commercial application of CCS is, according to fossil fuel companies, still at least a decade away, meaning that the global carbon budget could be used up "before CCS can even start to make a contribution"[198].

Thus if society decides to limit carbon emissions the confidence of those, such as Ridley, in the abundance of reserves as a basis for optimism with regards to wealth creation, and in technology to fix the gaps, are called into severe questioning. Deciding what we are going to burn the carbon budget *for* is a follow-on question.

Even if climate change were not an issue, the WWF 2010 Living Planet Report[199] analyses a range of additional stresses on critical ecosystem services, warning that if we continue business-as-usual we will likely face a host of other inter-related crises, which climate change will only exacerbate further. This is due to the fact that our demands on the earth's resources have grown exponentially - our "Ecological Footprint" has doubled since the 1960s alone, exceeding the earth's biocapacity by 50% in 2007.[200] Projecting ahead on the same pathway, the outlook is "serious" as "even with modest UN projections for population growth, consumption and climate change, by 2030 humanity will need the capacity of two earths to absorb CO_2 waste and keep up with natural resource consumption"[201]. The pressure points examined include biodiversity decline, water scarcity, and competition for land, with implications for food production.

Using the 'Living Planet Index', WWF highlight that biodiversity trends have been on a consistent decline since 1970 – decreasing globally by 30% by 2007.[202] In the tropics, this decline has reached as much as 60%, while in the temperate regions, it is almost 30%. The report finds that there are five major threats to biodiversity, and thus the life-supporting ecosystem services which it provides[203]: 1) Habitat loss, alteration and fragmentation from conversion of land for agriculture, aquaculture, and industrial or urban use as well as the effects of damming, irrigation systems, hydropower projects, and damaging fishing activities on water habitats; 2) Over-exploitation of wild species populations for food, materials or

[195] Ibid, p.6
[196] Ibid
[197] Ibid, p.9
[198] Ibid, p.12
[199] WWF, *Living Planet Report 2010: Biodiversity, biocapacity and development* (Switzerland: WWF International, 2010)
[200] Ibid, p.8
[201] Ibid, p.9
[202] Ibid, p.6
[203] Ibid, p.12

medicine at a rate faster than their reproductive capacity; 3) Pollution largely from excessive use of fertiliser and pesticides in agriculture and aquaculture, as well as urban and industrial effluents and mining waste; 4) Climate change; and 5) Invasive species which become competitors, predators or parasites of native species. The report finds that the drivers behind these threats are "human demands for food, drink, energy and materials, as well as the need for space for towns, cities and infrastructure"[204]. The scale of their impact depends on three factors: 1) population numbers (number of consumers); 2) consumption levels per capita; and 3) natural resource use efficiency levels. If these threats to biodiversity continue to grow unabated, the ecosystems will become stressed or degraded, potentially to a point of collapse. The warning is severe: "Crucially, the dependency of human society on ecosystem services makes the loss of these services a serious threat to the future well-being and development of all people, all around the world"[205].

In terms of water, the report finds that our use of freshwater ecosystem services is now "well beyond levels that can be sustained even at current demand"[206]. With demand projected to grow globally, whether through direct use or via consumption of material and agricultural goods, our impacts, including increased river fragmentation, over-abstraction and water pollution, are set to expand, exacerbated by climate change. Indeed, water is the "primary medium through which climate change influences the Earth's ecosystems"[207], in the likely form of melting glaciers, shifting precipitation patterns and increasingly intense and frequent droughts and floods. This will make water supplies less predictable at a time when pressure on water resources is only increasing. Freshwater scarcity, whether due to climate change, pollution or over-abstraction, will in turn impact severely on food production, which will also be hampered by increasing competition for land. Forests, biodiversity conservation, ecosystem processes, biofuels, cities, carbon storage and agricultural production all place demands on available land resources. Indeed, by 2050, following a business-as-usual pathway, combined land usage for both human and non-human needs would result in demands placed on the earth's resources equivalent to almost 3 planets worth.[208] WWF thus conclude that "land competition is likely to be a greater challenge in the future than conventional wisdom suggests"[209], particularly as the United Nations Food and Agriculture Organisation (FAO) project that a 70% increase in food production is required to meet future world needs[210].

Increasing crop yields is one possible response to this dilemma, however, the report expresses concern that future improvements may only be at half the historical rate, while climate change, land ownership issues, and socio-economic factors will probably limit the ability of innovations to deliver more food while using less land and water. A further challenge comes from changing dietary patterns globally. It is found that "if 9.2 billion people were to aspire to the equivalent of the diet of today's average Malaysian, we would still need 1.3 planets by 2050"[211]. With trends moving towards the world having a diet more like the average Italian – more meat, dairy and calories – the pressure on global land productivity is ever higher – closer to 2 planets worth.[212] Even converting forests to

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[204] Ibid
[205] Ibid
[206] Ibid, p.50
[207] Ibid, p.52
[208] Ibid, p.89
[209] Ibid, p.81
[210] Ibid, p.95
[211] Ibid, p.86
[212] Ibid, p.87

agricultural production does not provide enough land to grow the food needed for an Italian diet globally. Therefore, productivity must improve and we must decide how we are going to allocate land as an increasingly scarce resource, while reconsidering our diets. Thus, we are moving towards a world with increasing resource allocation tensions and scarcity.

4. Current evidence for resource constraints

Many commentators and reports use the term 'peak' to describe resource constraints. However, it is an often misused term. A non-renewable, finite resource reaches its peak in production when its maximum rate of extraction occurs. Thus 'peak' production does not necessarily mean running out of that resource, but often signifies the culmination point of its easy and ready availability.

4.1 Oil

4.1.1 What is the evidence for a resource constraint?

a) Demand is outstripping supply

BP's 2011 Statistical World Energy Review stated that oil consumption reached record levels in 2010 of 87.4 mb/d (million barrels per day), up 3.1% on the previous year.[213] At the same time, although global oil production increased by 1.8 m/bd, up 2.2%, this did not match the rapid growth in consumption.[214] Average daily crude oil consumption exceeded production by over 5 mb/d – the widest daily gap on record.[215] Although geopolitical and economic factors of course play a part, we can see that we need to go back 30 years – to 1981 – to find the last year where production outpaced consumption and that the general trend is a downward slope:

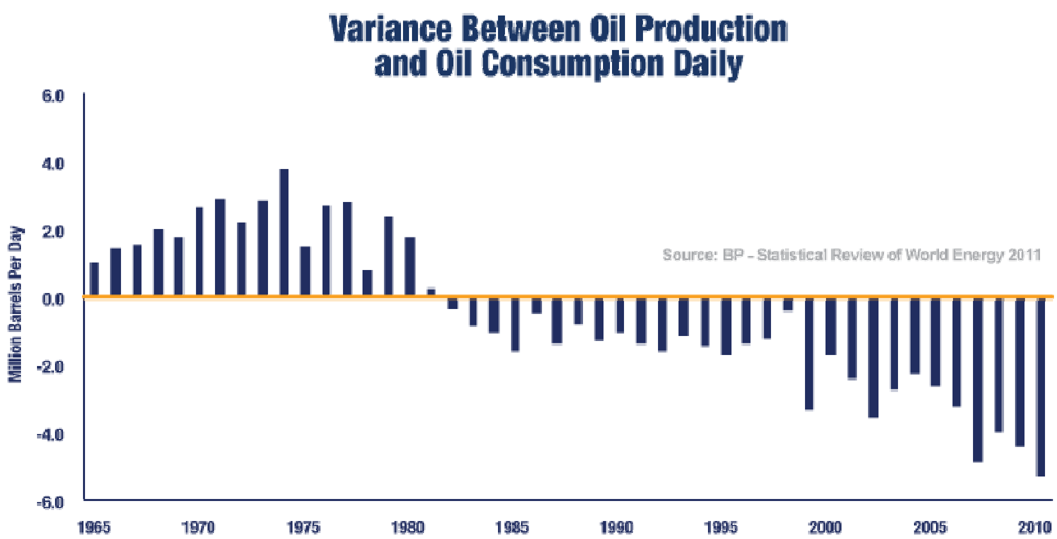

Figure 5: Variance Between Oil Production and Oil Consumption Daily[216]

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[213] British Petroleum (BP), *Statistical Review of World Energy 2011* (June 2011) <http://www.bp.com/assets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2011.pdf> [accessed March 2012]

[214] Ibid

[215] Ibid

[216] In Trey Cowan, 'Global Deficit Between Oil Consumption and Production Remains the Norm', *Rigzone* (June 13 2011) <http://www.rigzone.com/news/article.asp?a_id=107979 > [accessed March 2012] (Reproduced with permission.)

Projected demand is set to increase further, with the US EIA predicting that by 2035 total world energy demand will increase by 53%, a result of global population growth and rising living standards in non-OECD countries.[217]

b) Current reserves are not enough to meet this demand into the future – and yet-to-be found reserves are questionable

There is contention around current figures, and their reliability, concerning world oil reserves. The IEA argues that generally speaking the range of views on current world reserves is consistent, said to be at between around 1.2 – 1.3 trillion barrels in 2008[218], with the most recent figures placing it in the upper band of around 1.37 trillion[219]. The following graph displays the range of opinion explored by the IEA from a number of different sources:

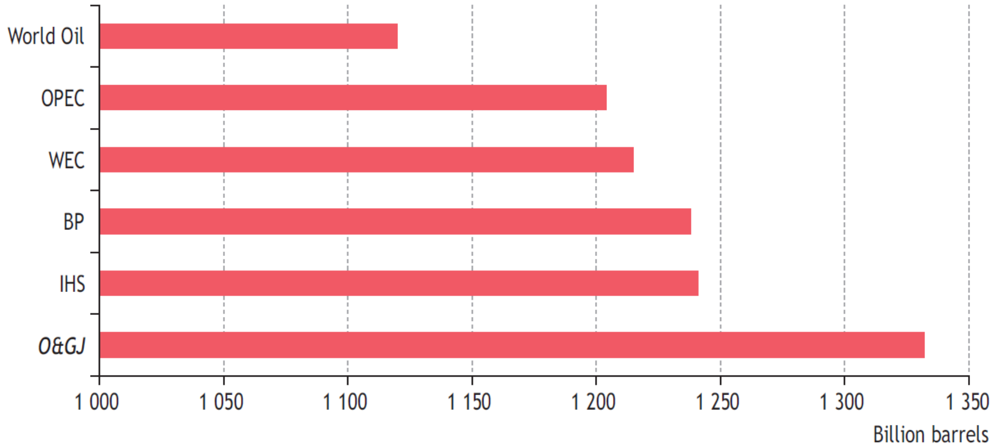

Figure 6: Estimated remaining world oil reserves, end-2007[220]

However, others, have since argued that these estimates are flawed and have revised down these projections to as low as between 850 – 900 billion barrels, providing as little as 27 years of supply at current consumption levels. [221] BP, more optimistically, places current reserves at 42 years of supply at current consumption rates.[222] The diverging opinions are based on differences of approach to methodology and definitions as much as accusations of wilful political distortion of numbers and of mis-reporting. An example of this was seen in

[217] U.S. Energy Information Administration (US EIA), 'International Energy Outlook 2011', *Independent Statistics & Analysis* (September 2011) <http://www.eia.gov/forecasts/ieo/pdf/0484(2011).pdf > [accessed March 2012]
[218] International Energy Agency (IEA), *World Energy Outlook*, (2008) <http://www.iea.org/textbase/nppdf/free/2008/weo2008.pdf> [accessed March 2012) p. 202
[219] IEA, *World Energy Outlook 2011* (2011) (Paris: OECD/IEA, 2011), p. 121
[220] In IEA, *World Energy Outlook 2008* (2008), (Paris: OECD/IEA, 2008), p. 202 (Reproduced with permission.)
[221] Energy Watch Group (EWG), *Crude Oil: The Supply Outlook*, Report to the Energy Watch Group, 3 (October 2007) <http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Oilreport_10-2007.pdf> [accessed March 2012]and N. A. Owen, O. R. Inderwildi and D.A. King, 'The Status of Conventional World Oil Reserves – Hype or Cause for Concern?', *Energy Policy*, Vol. 38, Issue 8 (August 2010) <http://www.sciencedirect.com/science/article/pii/S0301421510001072>[accessed March 2012] pp. 4743-4749
[222] BP, *Statistical Review of World Energy* (2011)

2009, when a whistleblower previously at the IEA stepped forward to say on-record that he believed published figures were deliberately inaccurate.[223]

To take a bigger picture view of overall trends, however, is to see that whichever figures are believed the message is the same. There is insufficient oil to meet projected demand. The following graph shows the projection of how the world is to meet the predicted growth of global oil demand of up to 120 mb/d by 2030 according to the IEA's 2008 WEO, with significant dependence on yet-to-be developed, yet-to-be found and unconventional oil and liquid fuels:

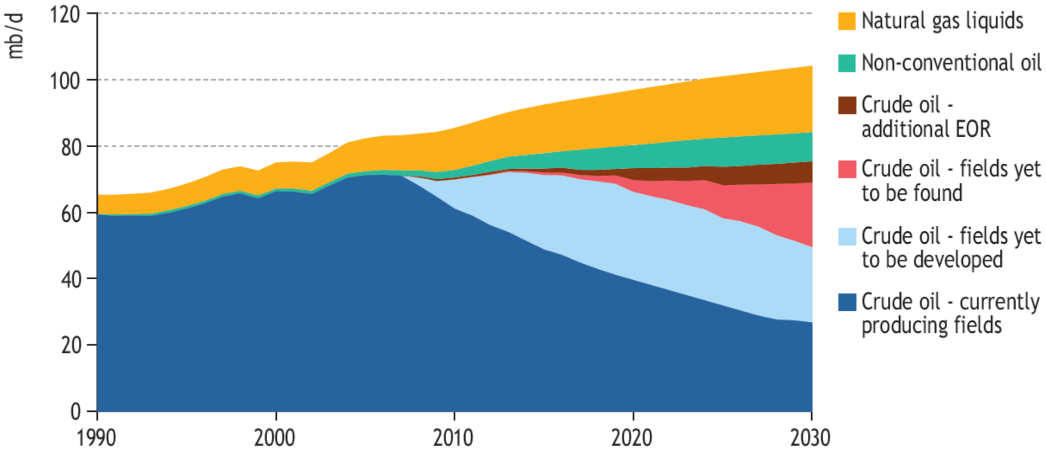

Figure 7: World oil production by source in the 2008 Reference Scenario[224]

However, as with data on current reserves, projected growth trends of alternatives to meet rising demand are also hotly disputed. The above data, for example, has been contested by a 2010 Swedish report from the University of Uppsala, which criticised the IEA's 2008 WEO for producing overstated projections and, based on its own analysis, revised the contributions of non-conventionals and yet-to-be-found fields significantly as charted below:

[223] Terry Macalister, 'Key Oil Figures were distorted by US Pressure', *The Guardian* (9 November 2009) <http://www.guardian.co.uk/environment/2009/nov/09/peak-oil-international-energy-agency> [accessed March 2012]

[224] In IEA, *World Energy Outlook 2008* (2008), p. 250 (Reproduced with permission.)

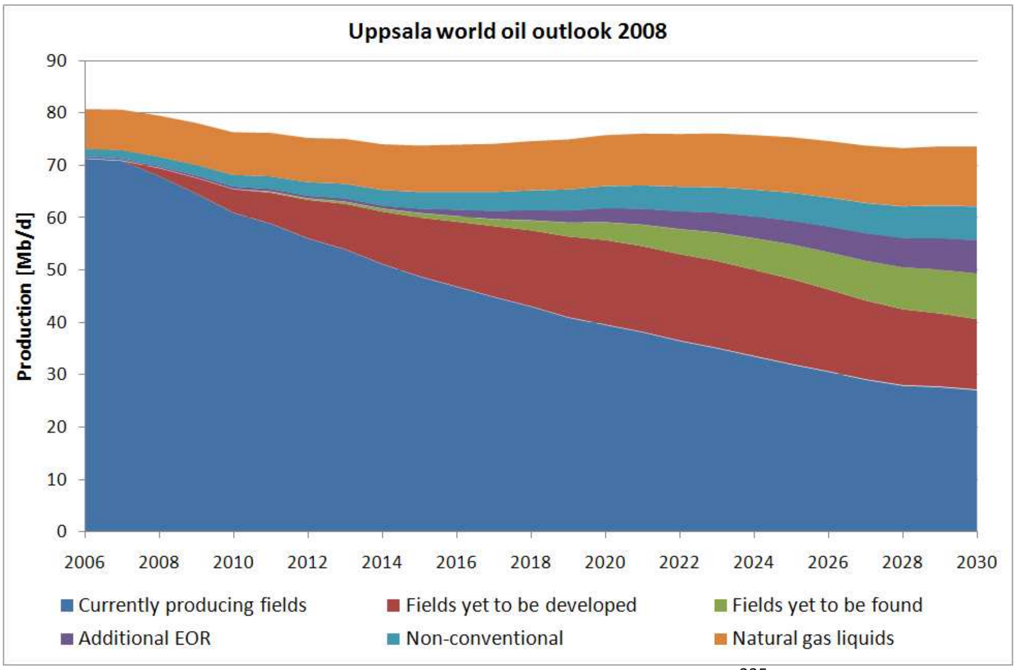

Figure 8: Uppsala world oil outlook 2008[225]

This graph from the report shows "Total oil production based on IEA (2008) data, but using realistic depletion rates of remaining recoverable resources, minor adjustments for non-conventional oil and recalculation of NGL to oil equivalents" and concludes that these "production volumes from fields yet to be developed or found should be regarded as optimistic."[226] In opposition to the IEA's scenario, the 'Uppsala World Oil Outlook 2008' predicts that in all cases, by 2030, oil production will be lower than today. Similarly, the Energy Watch Group in Germany has criticised IEA projections, also finding that by 2030, production is likely to be significantly less than that in 2005 at 39 Mb/d.[227] The discrepancy is shown in the graph below:

[225] In K. Aleklett, et al., 'The Peak of the Oil Age', *Energy Policy*, Vol. 38, Issue. 3 (March 2010) <http://www.tsl.uu.se/uhdsg/publications/peakoilage.pdf> [accessed March 2012] p. 26 (Reproduced with permission.)

[226] Ibid

[227] EWG, *Crude Oil* (October 2007) p. 13

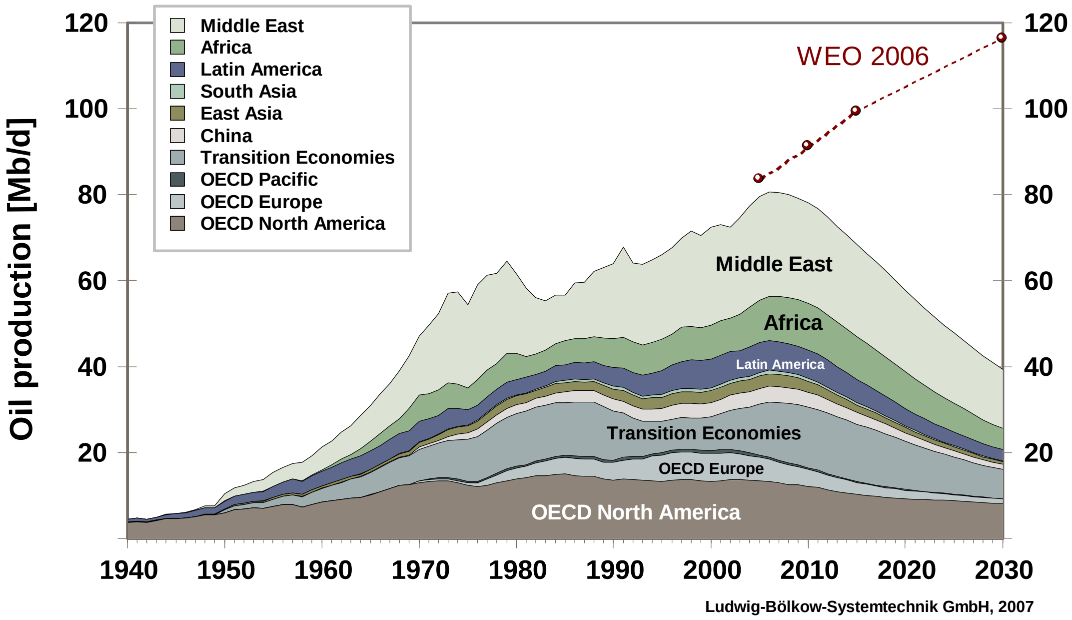

Figure 9: EWG oil production world summary[228]

c) Production is in general decline

The average global decline rate of existing conventional oil fields in production has been at least 4.5% year-on-year since 2003 (as depicted in the chart below), a trend which could be compounded, according to research by Merrill Lynch, by the global credit crisis's curb on investment into new fields.[229] They suggest that non-OPEC production may have already peaked as a result.

Each year, more and more fields transition into decline. In 2004, global oil production ceased to expand but instead new production only contributed to offsetting the decline in a rough plateau within a 4% fluctuation band.[230] One of the factors driving up decline rates is the fact that smaller, younger fields coming onto market decline at a much faster rate to the larger, older fields. The IEA estimates that oil fields typically decline at an average of 5.1% per annum after a peak in production has been reached.[231] However, the declines rates are inversely proportional to the size of the field, with super giants declining 3.4%, giant fields 6.5%, and large fields averaging a 10.4% decline per year.[232] With smaller fields becoming a growing proportion of global output, average decline rates are likely to accelerate in the near future.

[228] In ibid p. 12 (Reproduced with permission.)
[229] Merrill Lynch, 'Has non-OPEC Oil Production peaked?', *Global Energy Weekly* (3rd February 2009) <http://www.odac-info.org/sites/default/files/Has_non-OPEC_prodn_peaked.pdf> [accessed March 2012]
[230] Mikael Höök, et al., 'Giant oil field decline rates and their influence on world oil production', *Energy Policy*, Vol. 37, Issue 6 (June 2009) <http://www.tsl.uu.se/uhdsg/Publications/GOF_decline_Article.pdf> [acessed February 2012] p. 2
[231] IEA, *World Energy Outlook* (2008) p. 9
[232] Ibid

d) Discovery rates are lagging

Smaller fields will play a bigger part in future energy supply since the peak in discovery of giant conventional oil-fields, most now over 50 years old, was in the mid-1960s.[233] In 2005, these accounted for over 60% of world production, with the 20 largest fields solely responsible for nearly 25%.[234] Giant fields represent roughly 65% of the global ultimate recoverable conventional oil resources.[235] However, in 2007, the IEA found 16 of the top 20 giant fields to be in decline, with the chance of finding similar size fields now very remote.[236] Compounding this is the overall trend in reduced discovery of conventional fields generally. Geologist and Founder of the Association for the Study of Peak Oil & Gas (ASPO) Colin Campbell recently reported that since the mid-1980s, less oil has been found than we have consumed globally, even considering smaller fields:

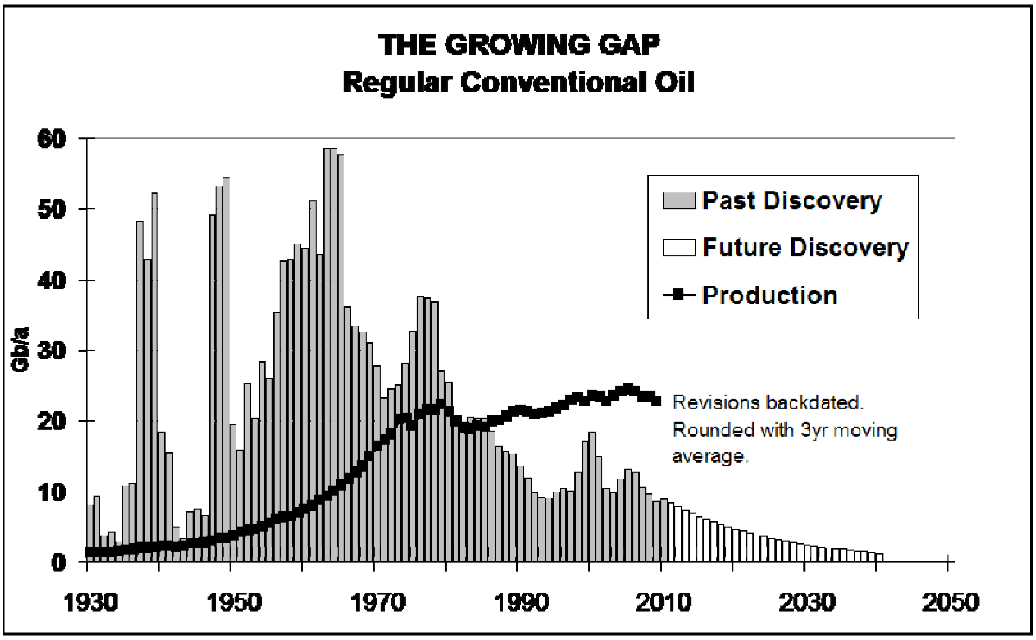

Figure 10: The growing gap: Regular Conventional Oil[237]

Prior to the global financial crisis only 14 out of 54 oil producing countries and regions in the world continued to increase conventional production, while 30 were past their production peak, with the remaining 10 having flat or declining production based on 2009 BP Statistical Review of World Energy data[238]. Total global oil production continued to grow to 2011 with 78% of oil production now in non-OECD countries[239].

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[233] Mikael Höök, et al., 'Giant oil field decline rates', *Energy Policy* (June 2009) p. 3
[234] Ibid
[235] Ibid
[236] Owen, Inderwildi and King, 'The Status of Conventional World Oil Reserves', (2010)
[237] In Colin Campbell, *Peak Oil Personalities*, (Skiberdeen, Ireland: Inspire Books, 2011) (Reproduced with permission.)
[238] In Praveen Ghanta, 'Is Peak Oil Real? A list of countries past peak', *True Cost blog (*14 July 2009) <http://truecostblog.com/2009/07/14/is-peak-oil-real-a-list-of-countries-past-peak/> [accessed March 2012] (Reproduced with permission.)
[239] BP Statistical Review 2012, http://www.bp.com/statisticalreview

Country	Peak Prod.	Peak Year
United States	11297	1970
Venezuela	3754	1970
Libya	3357	1970
Other Middle East	79	1970
Kuwait	3339	1972
Iran	6060	1974
Indonesia	1685	1977
Romania	313	1977
Trinidad & Tobago	230	1978
Iraq	3489	1979
Brunei	261	1979
Tunisia	118	1980
Peru	196	1982
Cameroon	181	1985
Other Europe & Eurasia	762	1986
Russian Federation	11484	1987*
Egypt	941	1993
Other Asia Pacific	276	1993
India	774	1995*
Syria	596	1995
Gabon	365	1996
Argentina	890	1998
Colombia	838	1999
United Kingdom	2909	1999
Rep. of Congo (Brazzaville)	266	1999*
Uzbekistan	191	1999
Australia	809	2000
Norway	3418	2001
Oman	961	2001
Yemen	457	2002
Other S. & Cent. America	153	2003*
Mexico	3824	2004
Malaysia	793	2004*
Vietnam	427	2004
Denmark	390	2004
Other Africa	75	2004*
Nigeria	2580	2005*
Chad	173	2005*
Italy	127	2005*
Ecuador	545	2006*
Saudi Arabia	11114	2005 / Growing

Canada	3320	2007 / Growing
Algeria	2016	2007 / Growing
Equatorial Guinea	368	2007 / Growing
China	3795	Growing
United Arab Emirates	2980	Growing
Brazil	1899	Growing
Angola	1875	Growing
Kazakhstan	1554	Growing
Qatar	1378	Growing
Azerbaijan	914	Growing
Sudan	480	Growing
Thailand	325	Growing
Turkmenistan	205	Growing
Peaked / Flat Countries Total	-	**60.6% of world oil production**
Growing Countries Total	-	**39.4% of world oil production**

* More information on these countries:

- Russian Federation – Russia's oil production collapsed by the early 90s as the Soviet Union collapsed, but despite a decade of growth, Russia's own oil executives do not think the old peak can be surpassed.
- India's production appears to have plateaued in 1995, and has stayed within a steady range since. The EIA forecasts Indian oil production to remain flat or decline slightly in the near future.
- Republic of Congo (Brazzaville) hit a production plateau in 1998, though current production is still very close to 1999 peak levels.
- Other Central & South America – The remaining countries of the Americas hit a production peak in 2003, though it is still too soon to know if this will be final peak.
- Malaysia has been on a production plateau since 1995, and the EIA projects flat or falling production.
- Other Africa – Oil production in much of Africa is potentially impacted by above-ground constraints, so it is definitely possible that production will rise here. It will rise from a low base of only 50,000 bpd however, and may not have much impact on total world production.
- Nigeria is impacted by domestic insurgencies in its oil-producing regions, and may be able to lift production if the political situation improves.
- Chad's oil production history is too short to definitively identify a peak in production, but the drop-off since 2005 has been dramatic.
- Italy has been on a production plateau for over 10 years, and it's unlikely that a mature economy is significantly under-exploiting its resource potential.
- Ecuador's production grew rapidly until 2004, but has leveled off and declined somewhat since then.

e) Cost of extraction is increasing while investment is slowing

The search to replace declining conventional oil fields has led to oil companies drilling wells in some of the most remote, inhospitable and technically difficult areas of the world, politically, geographically and in terms of infrastructure. As a result the cost of discovering each new barrel of oil has risen three-fold over the last decade.[240] According to a 2011 Reuters news article, the concern is that these rising costs may lead to an energy supply crunch as investment is squeezed due to greater inherent risks.[241] The higher price of oil, upwards of $70 a barrel, however, has made these high-cost explorations more attractive, indeed oil companies increased their budgets in 2011.[242]

However, in its World Economic Outlook 2011 report, the IMF warns that this predictable trend leading to a rise in drilling activity both offshore and on, does not mean the growing energy gap problem is solved – indeed, the lag between investment planning and delivery can be 10 years or longer, meaning that the turn around on current investments may not come to fruition for some time yet.[243] Lagging investment in the mid-1980s to mid-1990s thus still has its own current legacy effects, while investment today is also being hampered by rising costs and unexpected bottlenecks in oil investment services. The rising price of oil has triggered increased investment by some oil companies, but others are constrained by the tripling costs of extraction and short-term revenue considerations. A 'wait-and-see' approach characterises a significant number of investors who are also put off by changing legislative landscapes relating to taxation and ownership laws. Thus overall, the IMF predicts that "A return to the trend growth of 1.8% in oil production experienced during 1981–2005 seems unlikely at this point despite the current investment effort, given continued field declines in some major producers. In other words, prospects are for a downshift in the trend growth rate of oil supply."[244]

4.1.2 When will the constraint occur?

Predictions are varied. Some claim we are long past a peak, others, that a peak is up ahead in the coming decades, and yet others still that there is no such thing. The most recent predictions from key sources are summarised in the table below:[245]

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[240] Christopher Johnson, 'Oil exploitation costs rocket as risks rise', *Reuters* (11 February 2010) <http://www.reuters.com/article/2010/02/11/us-oil-exploration-risk-analysis-idUSTRE61A28X20100211> [accessed March 2012]

[241] Ibid

[242] Al Fin, 'High oil prices will lead to an oil exploration boom in 2011', *Oil Price* (5 January 2011) <http://oilprice.com/Energy/Oil-Prices/High-Oil-Prices-Will-Lead-to-an-Oil-Exploration-Boom-in-2011.html> [accessed March 2012]

[243] International Monetary Fund (IMF), 'Oil Scarcity, Growth and Global Imbalances', *World Economic Outlook: Tensions from the two-speed recovery* (April 2011)<http://www.imf.org/external/pubs/ft/weo/2011/01/pdf/c3.pdf> [accessed March 2012]

[244] Ibid p. 99

[245] For further examples of peak oil predictions see Robert L. Hirsch, *Peaking of World Oil Production: Recent Forecasts* (5 February 2007) <http://www.netl.doe.gov/energy-analyses/pubs/Peaking%20of%20World%20Oil%20Production%20-%20Recent%20Forecasts%20-%20NETL%20Re.pdf> [accessed March 2012] and
Boyle, Godfrey and Roger Bentley, *Global oil depletion: forecasts and methodologies. Environment and Planning B*, Vol. 35, Issue 4 (Open University, 2008) <http://oro.open.ac.uk/3957/1/Oil__Forecasts_and_Methodologies_-_Ver_6.13_PDF.pdf> [accessed March 2012] pp. 609–626

	World Peak Estimate	Source	Date of prediction
Before 2012	2005	Association for the Study of Peak Oil & Gas[246]	2009
	2006	Energy Watch Group[247]	2007
	Conventional crude – 2006	IEA[248]	2010
	2008	Aleklett, Höök, Jakobsson, Lardelli, Snowden, Söderbergh (Uppsala University, University of Adelaide, University of Liverpool)[249]	2010
	2009	Macquarie Group Ltd[250]	2009
	2011	Oil Depletion Analysis Centre[251]	2007

246 Kjell Aleklett, *The Peak Oil Year 2009* (2 January 2010) <http://www.peakoil.net/headline-news/the-peak-oil-year-2009> [accessed March 2012]
247 Energy Watch Group, *Crude Oil* (October 2007)
248 Stuart Staniford, 'IEA acknowledges peak oil', *Early Warning* (10 November 2009) <http://www.energybulletin.net/stories/2010-11-11/iea-acknowledges-peak-oil> [accessed March 2012]
249 K. Aleklett, et al., 'The Peak of the Oil Age', *Energy Policy* (March 2010)
250 David Sheppard, 'Peak oil expected in 2009', *Globe & Mail*, (16 September 2009) <http://www.theglobeandmail.com/globe-investor/peak-oil-expected-in-2009-macquarie/article1289428/> [accessed March 2012]
251 Daniel Howden, 'World oil supplies are expected to run out faster than expected, warn scientists', *The Independent* (14 June 2007) <http://www.independent.co.uk/news/science/world-oil-supplies-are-set-to-run-out-faster-than-expected-warn-scientists-6262621.html> [accessed March 2012]

By 2020	2013	French Economics, Industry & Finance Ministry[252]	2005
	2014 or sooner	Skrebowski (Director, Peak Oil Consulting, Founding Member, Association of the Study of Peak Oil)[253]	2011
	by 2015	UK Industry Task Force on Peak Oil & Energy Security (ITPOES)[254]	2010
	2015	Van de Veer (CEO, Shell)[255]	2008
	2017/2018	Maxwell (Industry Analyst)[256]	2010
	Before 2018 (worst-case, 2008)	Robelius (Uppsala University)[257]	2007
	All-liquids peak in 2018	PFC Energy[258]	2005
	Before 2020	UK Energy Research Centre[259]	2009
	By 2020	Shell, Signals & Signposts[260]	2011
	Before 2020	Ricardo Consulting[261]	2011
	Before 2020	Li (University of Utah)[262]	2011
	2020	Birol (Chief Economist, IEA)[263]	2009

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[252] Adam Porter, 'Peak Oil enters mainstream debate', *BBC News* (10 June 2005) <http://news.bbc.co.uk/1/hi/business/4077802.stm> [accessed March 2012]

[253] 'Peak Oil: Just Around the Corner', *Radio National – The Science Show* (23 April 2011) <http://www.abc.net.au/rn/scienceshow/stories/2011/3198227.htm> [accessed March 2012]

[254] ITPOES, *The Oil Crunch* (February 2010), <http://peakoiltaskforce.net/wp-content/uploads/2010/02/final-report-uk-itpoes_report_the-oil-crunch_feb20101.pdf> [accessed March 2012]

[255] Jeroen van de Veer, 'Letter to Shell Employees', *The Oil Drum* (22 January 2008) http://www.theoildrum.com/node/3548#more [accessed March 2012]

[256] Mathew Wild, 'Oil analyst tells Forbes: Peak oil by 2012', *Peak Generation* in *The Energy Bulletin* (30 September 2010) <http://www.energybulletin.net/stories/2010-09-30/oil-analyst-tells-forbes-peak-oil-2017> [accessed March 2012]

[257] Uppsala University, 'World Oil Production Close To Peak', *ScienceDaily* (30 March 2007) http://www.sciencedaily.com/releases/2007/03/070330100802.htm [accessed March 2012]

[258] Boyle, Godfrey and Bentley, *Global oil depletion*, Vol. 35, Issue 4 (Open University, 2008)

[259] Steve Sorrel, et al., *An assessment of the evidence for a near term peak in global oil production* (August 2009) <www.ukerc.ac.uk/support/tiki-download_file.php?fileId=283> [accessed February 2010]

[260]Shell International BV, *Shell Energy Scenarios to 2050: Signals and Signposts* (2011) <http://www-static.shell.com/static/aboutshell/downloads/aboutshell/signals_signposts.pdf> [accessed March 2012]

[261]'Ricardo study suggests global oil demand may peak before 2020', *PR Newswire* (7 November 2011) <http://www.prnewswire.com/news-releases/ricardo-study-suggests-global-oil-demand-may-peak-before-2020-133363593.html> [accessed March 2012]

[262] Dr Minqi Li, *Peak Energy and the limits to global economic growth* (University of Utah, July 2011) <http://www.econ.utah.edu/~mli/Annual%20Reports/Annual%20Report%202011.pdf> [accessed March 2012]

[263] George Monbiot, 'When will the oil run out?', *The Guardian* (15 December 2008) <http://www.guardian.co.uk/business/2008/dec/15/oil-peak-energy-iea> [accessed March 2012]

By 2030	Next 10 - 20 years	World Energy Council[264]	2007
	before 2030	IEA[265]	2009
	2028	Hirsch (for the US Department of Energy)[266]	2005
	After 2030 - "undulating plateau", peak "highly questionable"	CERA[267]	2006
After 2030	By 2060	HSBC[268]	2011
	Not before 2030	US EIA[269]	2004
	"Nowhere in sight"	Exxon Mobil[270]	2006

[264] 'Peak oil – September 19', *The Energy Bulletin* (19 September 2007) <http://www.energybulletin.net/node/34926> [accessed March 2012]
[265] '2020 Vision: The IEA puts a date on peak oil production', *The Economist* (10 December 2009) <http://www.economist.com/node/15065719> [accessed March 2012]
[266] Robert L. Hirsch, Robert Wendling and Roger Bezdek, *Peaking of World Oil Production: Impacts, Mitigation and Risk Management* (February 2005)<http://www.netl.doe.gov/publications/others/pdf/Oil_Peaking_NETL.pdf> [accessed March 2012]
[267] 'CERA says peak oil theory is faulty', *Energy Bulletin* (14 November 2006) <http://www.energybulletin.net/node/22381> [accessed March 2012]
[268] Ben Jervey, 'HSBC Bombshell: Oil Will Run Out in 50 Years', *Good* (1 April 2011) <http://www.good.is/post/hsbc-bombshell-oil-will-run-out-in-50-years/> [accessed March 2012]
[269] Erik L. Garza, 'The US Energy Information Administration's faulty peak oil analysis', *The Oil Drum* in *The Energy Bulletin* (August 2011) <http://www.energybulletin.net/stories/2011-08-19/us-energy-information-administrations-faulty-peak-oil-analysis> [accessed March 2012]
[270] Jeremy Leggett, 'Peak time viewing', *The Guardian* (15 March 200) <http://www.guardian.co.uk/commentisfree/2006/mar/15/peaktimeviewing> [accessed March 2012]

4.2 Coal

4.2.1 What is the evidence for a resource constraint?

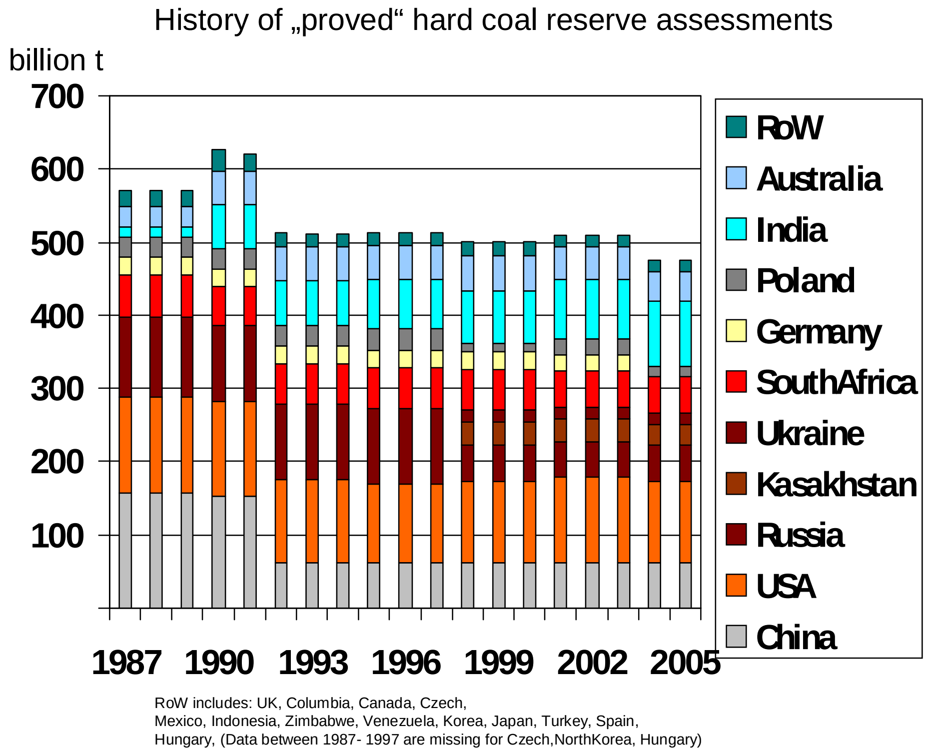
a) **Reserve data is overestimated, unreliable and has been continually downgraded since the 1980s**

The Energy Watch Group (EWG) have found that global reserve data on coal is generally of poor quality and often biased towards the high side with no objective way of determining data reliability.[271] They conclude that on a global level statistics overestimate both reserve and resource quantities. The most significant trend is the fact that both global resource and reserve data have overall been downgraded drastically over the past few decades, with reserve data the most critical one to watch. In 2004, Germany downgraded its proven hard coal (high quality coal) reserve data by 99%, from 23 billion tons to 0.183 billion tons.[272] Similarly, Poland has downgraded its hard coal reserves by 50% compared to 1997 levels.[273]

In other countries reserve data has not been updated for decades. Vietnam has not updated its data for 40 years; China, since 1992.[274] This is despite the fact that China has the fastest reserve depletion rate in the world, as the world's most dominating producer by a factor of two, of 1.9% per annum.[275] Russian reserve estimates have been constant since 1996.[276] In America, the second largest producer in the world, coal reserve figures are based on methods that have not been reviewed or revised since their inception in 1974, and much of the input data was compiled in the 1970s, leading, in 2007, to the Committee on Coal Research, Technology, and Resource Assessments to Inform Energy Policy at the National Research Council in the US calling for a "reinvigorated coal reserve assessment programme using modern methods and technologies to provide a sound basis for informed decision making."[277]

Although some countries have upgraded their hard coal reserves between 1987 – 2005 (India and Australia), other countries downgraded theirs by a combined total of 35% over the same period.[278] In the global sum, hard coal reserves have been downgraded by 15% over this time as shown below in the following EWG graph based on BP data:

[271] Energy Watch Group, *Coal: Resources and Future Production* (March 2007) <http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Coal_10-07-2007ms.pdf> [accessed March 2012]
[272] Ibid, p.4
[273] Ibid
[274] Dr. Minqi Li, 'Peak Coal and China', *The Oil Drum* (July 2011) <http://www.theoildrum.com/node/8064> [accessed March 2012]
[275] Energy Watch Group, *Coal: Resources and Future Production* (March 2007) p.6
[276] Mikael Höök, et al., 'Global coal production outlooks based on logistic model', Published in *Fuel*, Vol. 89, Issue 11 (November 2010) <http://www.tsl.uu.se/uhdsg/Publications/Coal_Fuel.pdf> [accessed March 2012] p. 22
[277] Committee on Coal Research, Technology, and Resource Assessments to Inform Energy Policy, National Research Council, *Coal: Research and Development to Support National Energy Policy* (2007) <http://www.nap.edu/catalog.php?record_id=11977> [accessed March 2012] p. 5
[278] Energy Watch Group, *Coal: Resources and Future Production* (March 2007)p.5 (Reproduced with permission.)



Source BP Statistical Review of World Energy 2006/ WEC 2004

Figure 11: History of "proved" hard coal reserve assessments[279]

The report states that “Adding all coal qualities from anthracite to lignite reveals the same general picture of global downgradings. The cumulative coal production over this period is small compared to the overall downgrading and is thus no explanation for it.”[280] BP has noted that the global coal reserve/production ratio has fallen dramatically since 2000, from 210 years of available coal to 118 years in 2011.[281]

A report published in the journal *Fuel* in November 2010 makes similar observations, highlighting the poor quality and likely over-estimation of reserve estimates, concluding that in general “the historical trend does not point toward any major increases in world coal reserves. In the best case, the reserves can be fairly stable, while they can continue to decrease in a less optimistic case.”[282] The report plots the evolution of world reserve estimates from two renowned sources – the World Energy Council (WEC) and the German Federal Institute for Geosciences and Natural Resources (BGR) – showing a general plateau or decline:

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[279] In ibid p. 22 (Reproduced with permission.)

[280] Ibid p. 5

[281] BP, *Statistical Review* (2011)

[282] Mikael Höök, et al., ‘Global coal production outlooks based on logistic model’, *Published in Fuel* (November 2010) p. 14

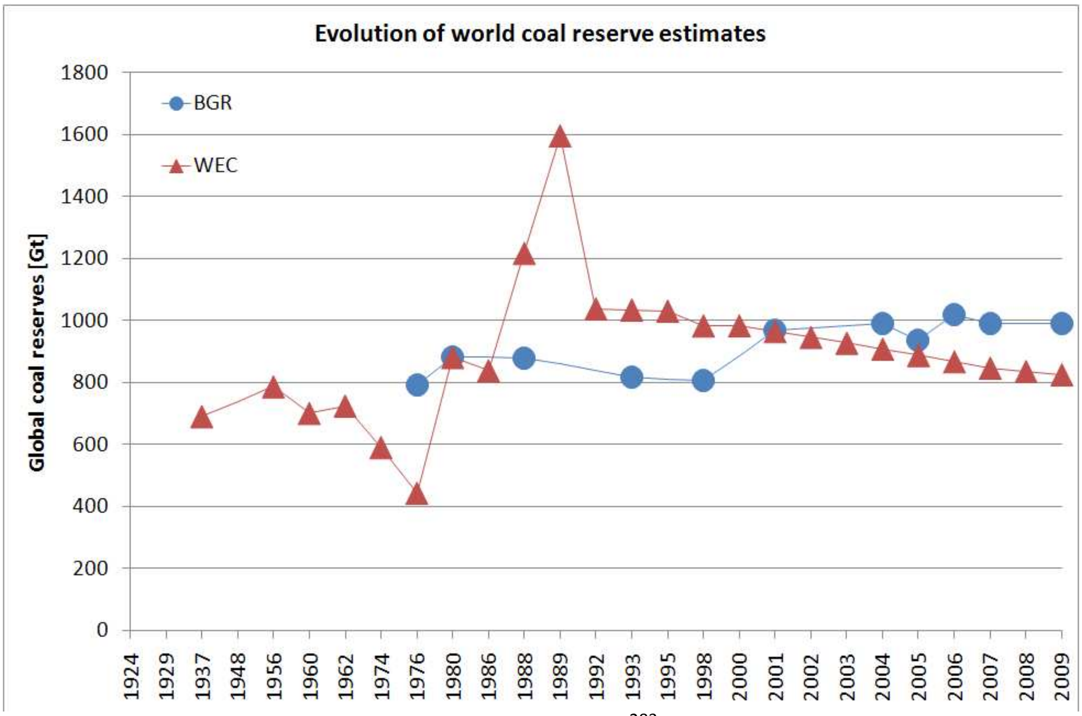


Figure 12: Evolution of world coal reserve estimates[283]. Annual global consumption is just below 1% of the total reserve estimate[284] and therefore cannot account for the trend.

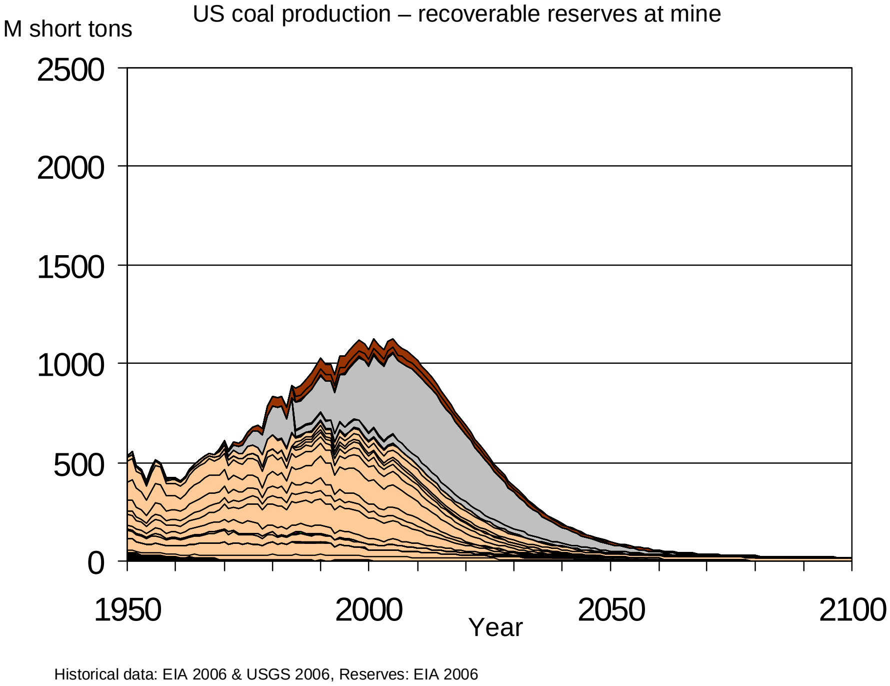
b) **Reserve data is not necessarily equivalent to what is practicable to produce**

A study by Patzek et al from the University of Texas explains that reserve estimates are less valuable as a basis for future projection of resource extraction than actual past and current production rates.[285] In a National Geographic interview he argues that the only estimate that's credible for assessing how much coal is practical to mine and use "is what actually comes out of the mines, and how you project that into the future."[286] For example, his study notes that estimations of Illinois's proven reserves are still high – the second highest recorded in the USA – even though production there has declined to less than half of what it was 20 years ago.[287] This is due to a combination of factors, including environmental legislation which has made mining of high-sulphur-content coal, like that found in Illinois, less attractive.

The Energy Watch Group found the same. Two out of three states containing over 60% of US reserves, that is Illionois and Montana, have been producing at very low levels compared to their stated reserves over the past 20 years. This is due to a variety of social, environmental and political factors. It is therefore "not probable" that the estimated reserves will ever be

283 In ibid p. 15 (Reproduced with permission.)
284 BP, *Statistical Review* (2011)
285 Gregory D. Croft and Tadeusz W. Patzek , 'A global coal production forecast with multi-Hubbert cycle analysis', *Energy*, Vol. 25, Issue 8 (August 2010) <http://www.sciencedirect.com/science/article/pii/S0360544210000617> [accessed March 2012]
286 Mason Inman, 'Mining the Truth on Coal Supplies', *National Geographic News* (8 September 2010) <http://news.nationalgeographic.com/news/2010/09/100908-energy-peak-coal/> [accessed March 2012]
287 Gregory D. Croft and Tadeusz W. Patzek , 'A global coal production forecast with multi-Hubbert cycle analysis', *Energy* (August 2010) p. 3111

converted into full production.[288] Of course if existing environmental legislation was relaxed or removed this could increase production from these mines (essentially allowing increased sulphur emissions). The below graphs show how coal production would develop if only the recoverable reserves at producing mines were used (left figure), and if all estimated additional recoverable reserves were produced (right figure) according to a bell shaped profile.



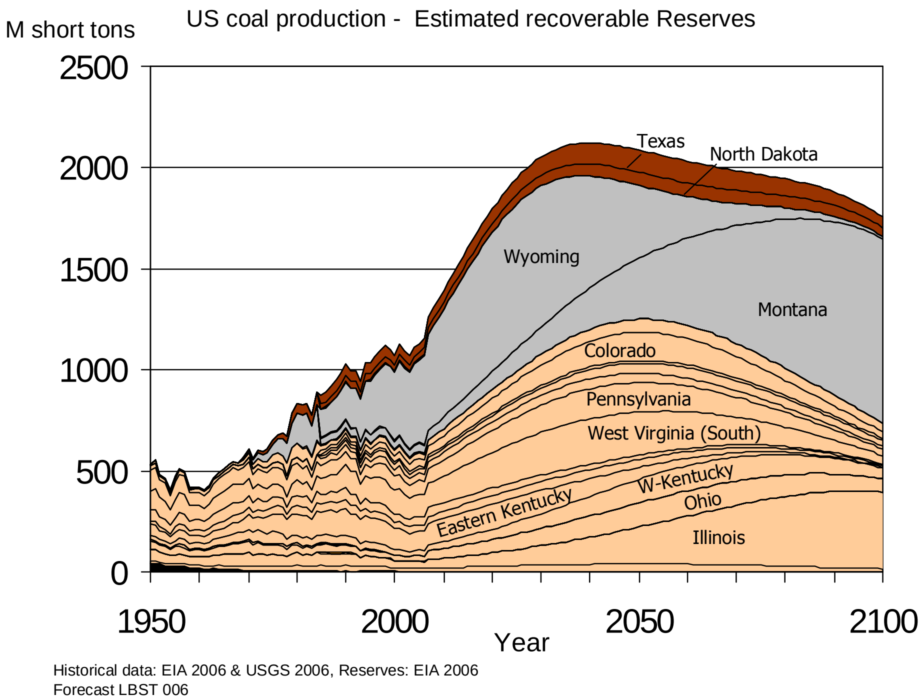


Figure 13: US coal production if only known recoverable reserves at mines are producible (top) and if all reported estimated recoverable reserves are producible (bottom).[289]

[288] Energy Watch Group, *Coal: Resources and Future Production* (March 2007) p.38
[289] In ibid p.36 (Reproduced with permission.)

In the first case, coal production would decline rapidly. Both graphs show that any future increase of US coal production requires huge investments into new mines, especially in Montana and Illinois. However, the report concludes that a realistic production profile will have to be somewhere between the two extremes.

c) **Higher quality coal is being depleted most rapidly, with increasing production of lower-quality, lower-energy-providing coal and increasing reliance on harder-to-access reserves**

According to the BP 2011 *Statistical Review of World Energy*, at the end of 2010, the world (excluding China) had 746.4 billion tons of coal reserves.[290] However, out of these total coal reserves, 403.9 billion tons were sub-bituminous and lignite coal, which is coal with low energy content and economic value; only 342.6 billion tons were anthracite and bituminous coal of higher quality.[291] The IEA Clean Coal Centre also states that around half of world coal reserves are comprised of low value coals, predominantly lignites, subbituminous coals, and high-ash bituminous coals.[292] The energy content per unit mass of mine-run lignite is about a third that of anthracite.[293] The highest quality coal is being depleted the quickest, particularly as demand for the fuel is growing.[294] Reliance on low-value coal is a result often of increasing exhaustion of reserves of higher grade coals and the pursuit of national energy security. This depletion of 'easy coal' can be seen as the end of abundant cheap coal. On this basis, a study by Patzek et al predicts that the global peak of coal production in terms of energy content will be in 2011, resulting in a fall of production of 50% of its peak value over the next 40 years.[295]

Contributing to this is the fact that the world is increasingly relying on harder to access reserves. According to coal geologist Graham Chapman, in China, much of the remaining coal is more than 1000 metres below the surface, while in South Africa the geology is extremely complex.[296] In 2009, the US Geological Survey reported a general shift towards deeper mining of thinner beds in the older Eastern US coalfields because of the exhaustion of surface-minable coal, and a resulting decline in production. [297] Western US production from cheaper surface mining has now surpassed Eastern US production.

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[290] BP, *Statistical Review* (2011)
[291] Dr. Minqi Li, 'Peak Coal and China', *The Oil Drum* (July 2011)
[292] Steve Mills, 'Global Perspectives on the use of low quality coals', *IEA Clean Coals Centre* (January 2011) <http://www.iea-coal.org.uk/site/2010/publications-section/newsletter-information/current-newsletter/coal-prospects-in-the-european-union> [accessed March 2012]
[293] Gregory D. Croft and Tadeusz W. Patzek , 'A global coal production forecast with multi-Hubbert cycle analysis', *Energy* (August 2010) p. 3115
[294] Richard Heinberg and David Fridley, 'The End of Cheap Coal', Post Carbon Institute (14 July 2011) <http://www.postcarbon.org/article/406162-the-end-of-cheap-coal#> [accessed March 2012]
[295] Gregory D. Croft and Tadeusz W. Patzek , 'A global coal production forecast with multi-Hubbert cycle analysis', *Energy* (August 2010) p.3115
[296] David Strahan, 'Coal: Outlook for the black stuff', *New Scientist*, Issue 2639 (19 January 2008) <http://www.newscientist.com/article/mg19726391.800-coal-bleak-outlook-for-the-black-stuff.html> [accessed March 2012]
[297] Luppens, J.A., et al., 'Coal resource availability, recoverability, and economic evaluations in the United States—A Summary', in B.S. Pierce and K.O. Dennen, eds., *The National Coal Resource Assessment Overview: U.S. Geological Survey Professional Paper 1625–F* (2009) <http://pubs.usgs.gov/pp/1625f/downloads/ChapterD.pdf> [accessed March 2012] p. 17

This shift has made the mining and transportation of mined coal much more expensive and energy-intensive.

d) **As a result the energy returned on energy invested (EROEI) is falling**

The mining of lower-quality coal carries with it an 'energy penalty' as it is less energy dense and requires more energy in its production to avoid sulphur dioxide emissions. Coal already has one of the lowest EROEI ratios compared to other fuel sources[298], but the increasing use of lower-grade coal reduces this further. For example, a report by Richard Heinberg examining the net energy limits of various resources found that in the early 20th century, the net energy from US coal was very high, at an average of as much as 177:1 ratio, since when it has fallen substantially to a range of 50:1 to 85:1.[299] Globally the average estimate for EROEI of coal in 2012 is 28:1[300]. Moreover, the decline is continuing, with one estimate suggesting that by 2040 the EROEI for U.S. coal will be 0.5:1 – that is to say that more energy will be required to extract the resource than the resource will provide.[301] At this point, extraction is no longer economic.

In the USA, with almost 30% of the world's total coal reserves, US coal production has been found to have reached a peak in 1998 in terms of energy value, as opposed to tonnage, since when energy value has declined due to the increasing reliance on lower-quality subbituminous coal, with nearly all states producing high-quality coal in productive decline.[302] Concurrently, the heat value of American coal has declined over the past few decades. In 1955, the average heating value was 30.2 MJ/kg, while today it is only 20.5 MJ/kg – a decline of more than 30%.[303] Meeting projected energy production value forecasts, such as those given by the IEA for example, will thus require greater production volumes than those of today, particularly as heating value and coal quality decline is projected into the future, as the below graph from Uppsala University research indicates:

[298] Jamie Bull, 'EROEI of electricity generation', *oCo Carbon blog* (19 May 2010)<http://oco-carbon.com/2010/05/19/eroei-of-electricity-generation/> [accessed March 2012] Based on data from The Offshore Valuation Group, *The Offshore Valuation Report* <http://offshorevaluation.org/> [accessed March 2012]

[299] Richard Heinberg, *Searching for a Miracle: "Net Energy" limits and the fate of industrial society* (September 2009) <http://www.ifg.org/pdf/Searching%20for%20a%20Miracle_web10nov09.pdf> [accessed March 2012]

[300] Lambert, Hall, Balogh, Poisson & Gupta, 2012, *EROI of Global Energy Resources: Preliminary status and trends,* DFID - 59717

[301] Ibid

[302] Mikael Höök, et al., *A supply-driven forecast for the future global coal production* (2008) <http://www.tsl.uu.se/uhdsg/Publications/Coalarticle.pdf> [accessed March 2012] p. 18

[303] Ibid

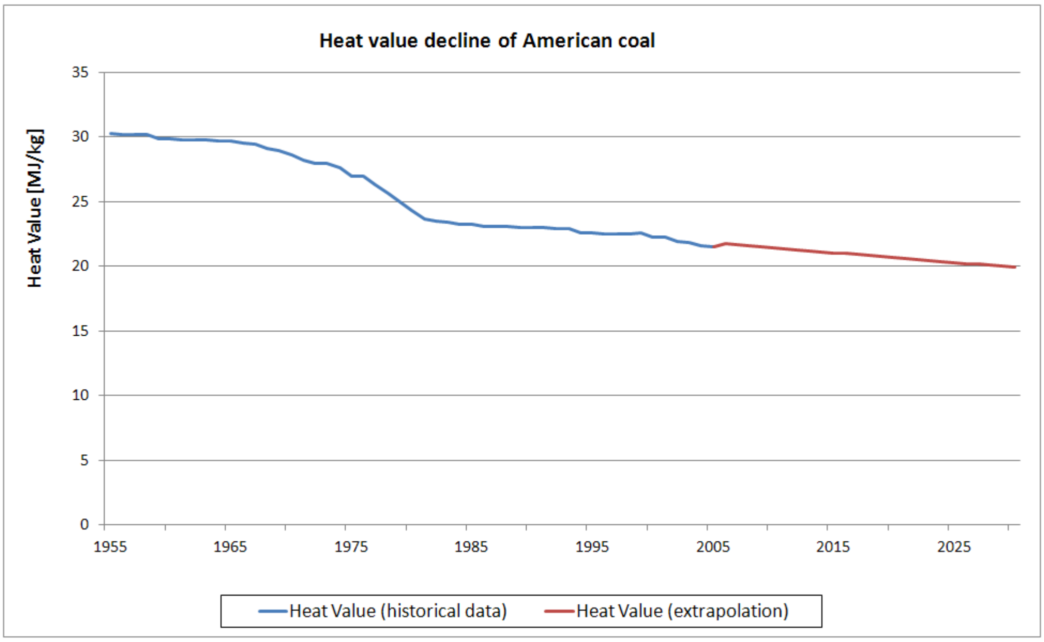

Figure 14: Heat value decline of American coal[304]

The Energy Watch Group have also observed a steady decline of coal quality worldwide, not only because of increasing reliance on lower quality decline, but also because of a decline in quality within each class of coal in general.[305]

e) **Declining productivity is offsetting gains from technological advances**

A 2008 study of 'Productivity in the Mining Industry' in Australia, which has 9% of the world's coal reserves[306], is the world's biggest coal exporter and where coal is the country's second highest export commodity[307], found that 'Multifactor Productivity' (MFP) of Australian mines had declined by 24% between 2000 - 2001 and 2006 - 2007.[308] A third of this decline was due to associated temporary lags in output due to long lead times in investment. However, this is against the background of ongoing depletion of Australia's resource-base, which on its own was "estimated to have had a significant adverse effect on long-term mining MFP. In the absence of observed resource depletion, the annual rate of mining MFP growth over the period from 1974 – 1975 to 2006 -2007 is estimated to have been 2.3%, compared with the measured rate of 0.01%."[309] This is despite the increase of capital and labour inputs observed over the same periods: [310]

[304] In ibid p. 24 (Reproduced with permission.)
[305] Energy Watch Group, *Coal: Resources and Future Production* (March 2007) p.32
[306] Mikael Höök, et al., 'Global coal production outlooks based on logistic model', Published in *Fuel* (November 2010)
[307] 'Facts and Figures', Australian Coal Association, <http://www.australiancoal.com.au/facts-and-figures.html> [accessed March 2012]
[308] D. Parham, H. Bloch, L. Soames, and V. Topp, 'Productivity in the Mining Industry: Measurement and Interpretation', *Productivity Commission Staff Working Paper* (December 2008) <http://www.pc.gov.au/__data/assets/pdf_file/0005/84911/mining-productivity.pdf> [accessed March 2012]
[309] Ibid p. XIV
[310] Ibid p. XVI

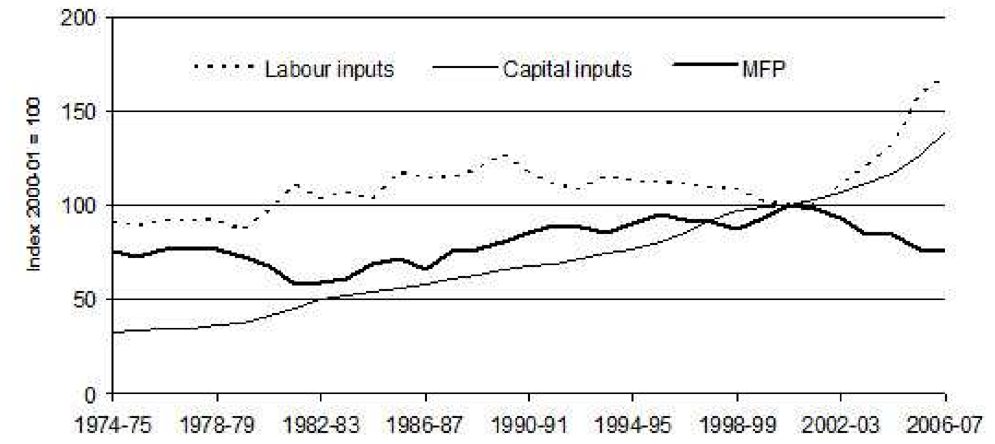

Figure 15: Mining industry MFP and primary inputs[311]

The report claims that changes in the quality of natural resource inputs are not usually taken into account when measuring MFP. However, the effect of mining lower-grade resources through more energy-intensive methods, due to increasing remoteness, inaccessibility and lower resource quality, is that over time more 'effort' is needed to produce the same unit of output. Thus, increasing inputs of labour and capital to achieve the same level of output shows up as declining productivity. The report demonstrates that removing the influence of depletion and the temporary effects of investment lead-times results in a positive outlook on MFP – a growth of 2.3% per annum over the past 32 years thanks to improvements in efficiency, management and technological advances.[312] However, factoring in these impacts results in a very different picture: [313]

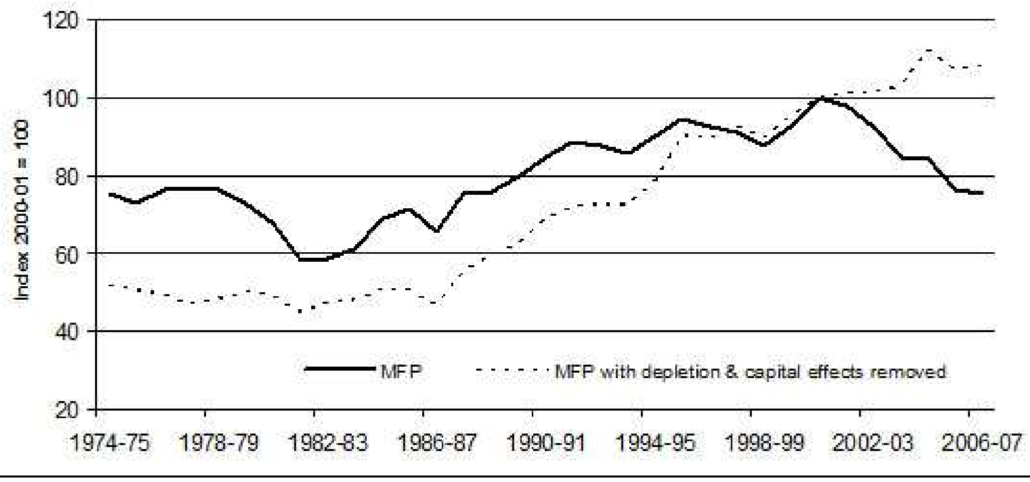

Figure 16: Mining MFP with depletion and capital effects removed[314]

Höök et al at Uppsala University concur that "better extraction technologies have been found to be largely obscured by decreasing reserve levels as the coal becomes increasingly

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[311] In ibid (Reproduced with permission.)

[312] Ibid p. XXI

[313] Ibid p. XXII

[314] In ibid (Reproduced with permission.)

complicated to mine, effectively meaning that depletion has been able to offset many of the gains from new technology."[315]

In the USA, Höök's team also find that productivity, as measured by tons per miner, is also in decline, due to the increased effort required for extraction. While productivity has improved in the past following dips, for example, after 1960 – 1970, their report submitted to the Association for the Study of Peak Oil & Gas in 2008 questions the likelihood of reversing the current decline.[316] In 2009, the EIA's Annual Energy Review similarly revealed that productivity, following significant improvements since the 1970s, has been in steady decline in the US since 2000, placing the US energy-production peak of coal in that year: [317]

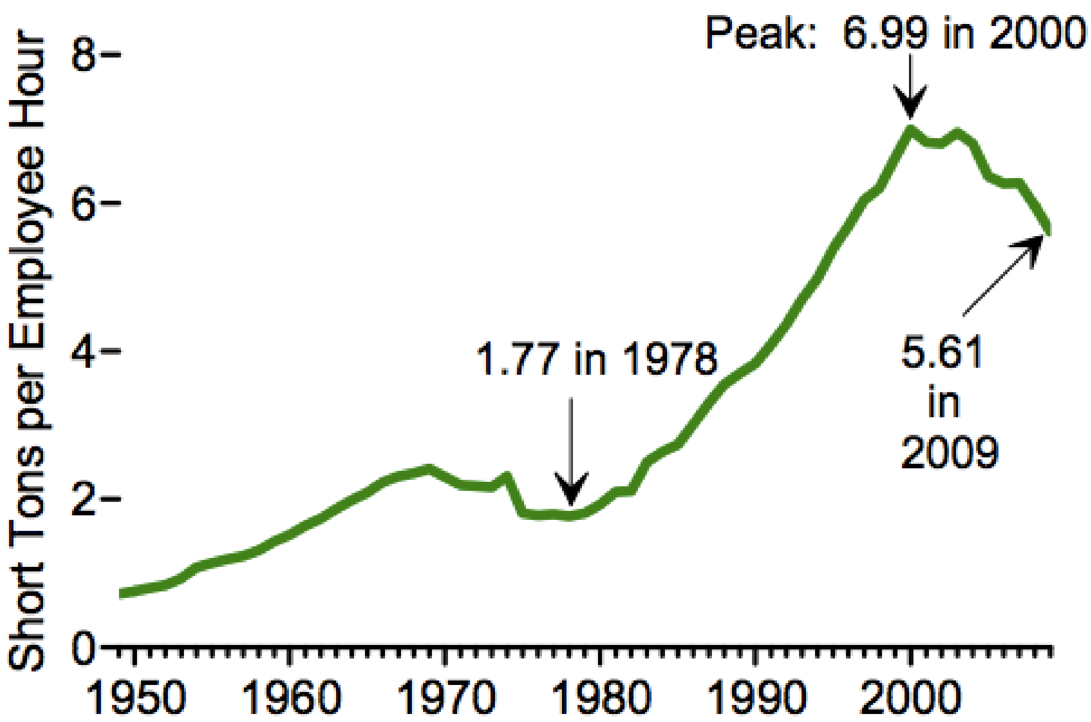

Figure 17: US coal mining productivity[318]

The Australian Productivity Commission report notes that as the index of commodity prices increased between 2006 – 2007, investment into capital and labour inputs in the mining sector also increased, but without a matching increase in output.[319] This implies that increasing investment fuelled by a rising price of coal does not always translate into productive gains in energy terms.

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[315] Mikael Höök, et al., 'Global coal production outlooks based on logistic model', Published in Fuel (November 2010) p.5

[316] Mikael Höök, et al., A supply-driven forecast for the future global coal production (2008) p. 24

[317] US Energy Information Administration, *Annual Energy Review* (2009) <http://www.eia.gov/totalenergy/data/annual/pdf/perspectives_2009.pdf> [accessed March 2012] p. XXIX

[318] In ibid

[319] D. Parham, H. Bloch, L. Soames, and V. Topp, 'Productivity in the Mining Industry', *Productivity Commission Staff Working Paper* (December 2008) p.XVI

f) Production has already peaked in a number of countries, with dependence on the Big Six, especially China, pivotal

Peak coal production has already occurred in around 20 countries, including in the UK, Germany and Japan and the combined production volume has declined since 1980 by almost 50% from 1200 Mt to 620 Mt in 2006.[320]

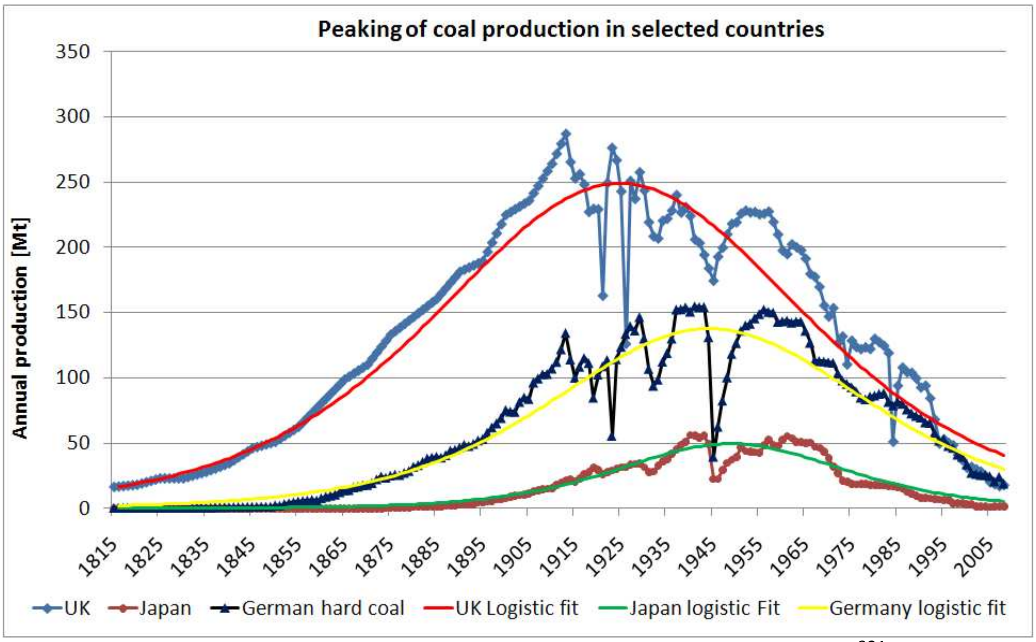

Figure 18: Peaking of coal production in selected countries[321]

The world is reliant on six nations who together have over 90% of world coal reserves – USA, Russia, India, China, Australia and South Africa. The world is therefore reliant on the production possibilities of these countries – specifically that of China, which dominates world production. With only 14% of global coal reserves, in 2010, China accounted for 43% of world production in volume[322] with an annual depletion rate of 1.9%[323].

[320] Mikael Höök, et al., 'Global coal production outlooks based on logistic model', Published in *Fuel* (November 2010) p.5

[321] In ibid, p. 3 (Reproduced with permission.)

[322] Dr Minqi Li, *Peak Energy and the limits to global economic growth* (University of Utah, July 2011) p. 10

[323] Energy Watch Group, *Coal: Resources and Future Production* (March 2007) p. 6

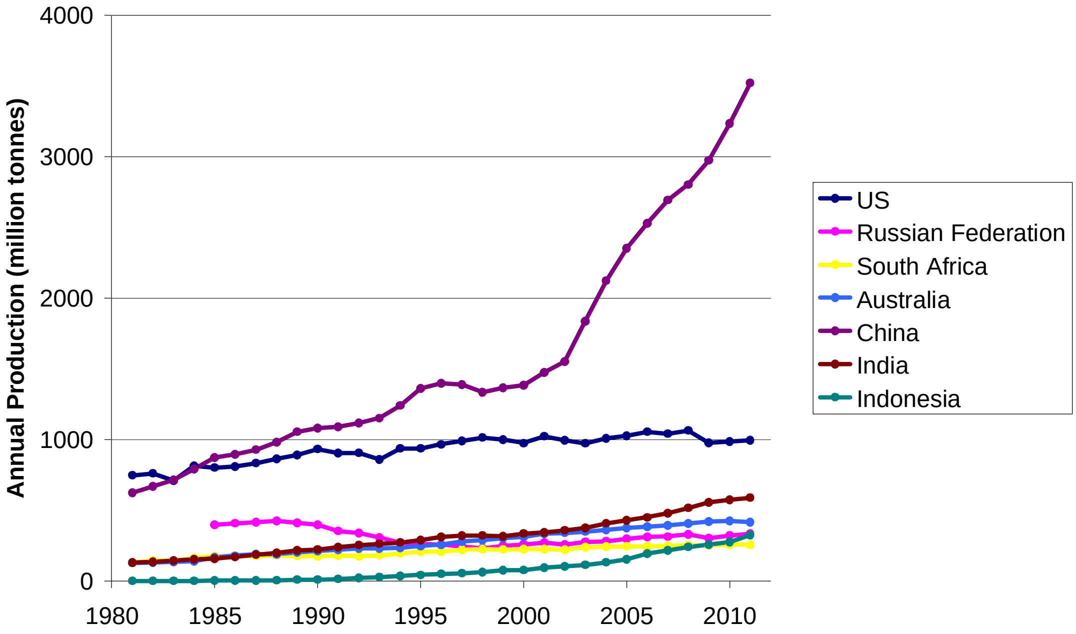

Figure 19: World's largest coal producers (annual production above 250 million tonnes), 1981 - 2011 (based on BP *Statistical Review of World Energy* 2012 data)

Some estimates have placed Chinese peak coal production before 2020.[324] However, with voracious demand within the country alone rapidly increasing – already standing at 47% of global consumption – this could come much sooner.[325] As a result Beijing are considering placing a cap on national production to slow peaking and conserve their precious resource base.[326]

4.2.2 When will the constraint occur?

There has been a recent spate of published research in which forecasts of 'peak coal', a fairly new concept, have been made. Of course, there are disagreements about methodology and assumptions made, and a range of estimates is the result as shown below.

[324] Ibid

[325] Jeff Rubin, 'Is Peak Coal Coming?', *The Globe and Mail* (27 April 2011) <http://www.theglobeandmail.com/report-on-business/commentary/jeff-rubins-smaller-world/is-peak-coal-coming/article1999004/> [accessed March 2012]

[326] David Winning, 'China's Coal Crisis', *The Wall Street Journal* (16 November 2010) <http://online.wsj.com/article/SB10001424052748704312504575617810380509880.html?mod=googlenews_wsj

	World Peak Estimate	Source	Date of prediction
By 2020	By 2011 (energy terms), by 2015 (mass)	Patzek & Croft (University of Texas; University of California, Berkeley)[327]	2010
By 2030	By 2025	Energy Watch Group[328]	2007
	2048 (mass); between 2011 – 2047 (energy)	Mohr & Evans (University of Newcastle, Austalia)[329]	2009
	Between 2020 - 2050	Höök, Zittel, Schindler & Aleklett (Uppsala University, Ludwig Bölkow Systemtechnik GmbH)[330]	2010
	90% exhaustion by 2070. Suggested extrapolated peak well before.[331]	Rutledge (California Institute of Technology)[332]	2011
	Before 2030	Li (University of Utah)[333]	2011
No peak on the horizon	Undefined – production still climbing up to 2100 in many scenarios	IPCC[334]	2007
	Not a grave concern	Summers[335]	2010
	Coal to last another 118 years	World Coal Institute[336]	2011

[327] Gregory D. Croft and Tadeusz W. Patzek , 'A global coal production forecast with multi-Hubbert cycle analysis', *Energy* (August 2010)
[328] Energy Watch Group, *Coal: Resources and Future Production* (March 2007)
[329] http://dancass.com/static/files/assets/cced3021/GME_2009_J85.pdf> [accessed February 2021]
[330] Mikael Höök, et al., 'Global coal production outlooks based on logistic model', Published in *Fuel* (November 2010)
[331] Luis de Sousa, 'Peak Coal: the Olduvai perspective', *The Oil Drum* in *The Energy Bulletin* (10 January 2011) <http://www.energybulletin.net/stories/2011-01-11/peak-coal-olduvai-perspective> [accessed March 2012]
[332] David Rutledge, 'Estimating long-term world coal production with logit and probit transforms', *International Journal of Coal Geology*, 85 (2011) <http://www.its.caltech.edu/~rutledge/DavidRutledgeCoalGeology.pdf> [accessed March 2012] pp. 23-33
[333] Dr Minqi Li, *Peak Energy and the limits to global economic growth* (University of Utah, July 2011)
[334] Dave Rutledge, The Coal Question and Climate Change, *The Oil Drum* (25 June 2007) <http://www.theoildrum.com/node/2697> [accessed March 2012]
[335] Heading Out, 'Future Coal Supplies - More, Not Less', *The Oil Drum* (24 November 2010) <http://www.theoildrum.com/node/7129> [accessed March 2012]
[336] World Coal Association, 'Coal', <http://www.worldcoal.org/coal/> [accessed March 2012]

4.3 Natural Gas

4.3.1 What is the evidence for a resource constraint?

a) Mean discovery has peaked and is falling

In 2002, Exxon Mobil Vice President, Harry J. Longwell placed the peak of global gas discovery around 1970, observing a sharp decline in natural gas discovery rates since then.[337] This is depicted in the graph by petroleum engineer Jean Laherrère below. The rate of discovery fell below the rate of consumption in 1980 and the gap has been widening since. Overall, despite significant investment, some recent finds, and rising production, conventional natural gas reserves are not increasing.

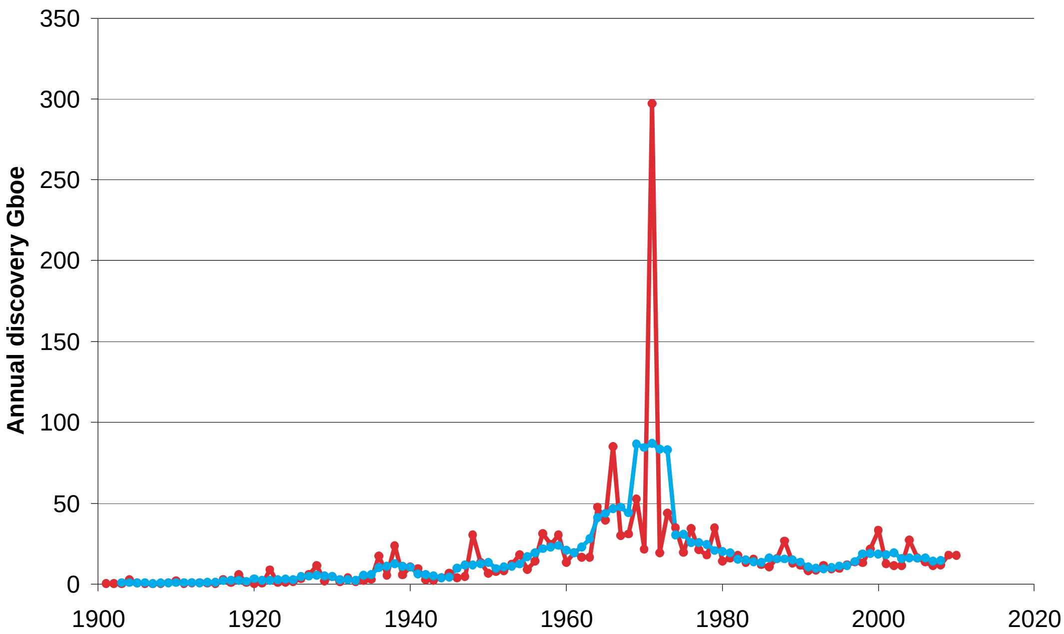

Figure 20: World conventional gas annual mean discovery in red and smoothed 5 year discovery in blue (Giga barrels of oil equivalent).[338]

Generally speaking, data on reserves is cloudy with contention over reliability, definitions and methodology as in the case of oil. In 2004, Laherrère thus mapped technical (proven and probable sources) versus proven reported reserve data onto a chart, showing that there was a plateau from the 1980s in technical reserves. However, recent data from BP shows an increase in gas reserves estimates above this plateau due to the inclusion of further unconventional sources.

[337] Harry J. Longwell, 'The Future of the Oil and Gas Industry: Past Approaches, New Challenges', *World Energy*, Vol. 5, Issue 3 (2002) <http://www.worldenergysource.com/articles/pdf/longwell_WE_v5n3.pdf> [accessed March 2012] p. 101

[338] Jean Laherrère, *Future of natural gas supply* (May 2004) <http://www.peakoil.net/JL/JeanL.html> .Updated data supplied by Jean Laherrère

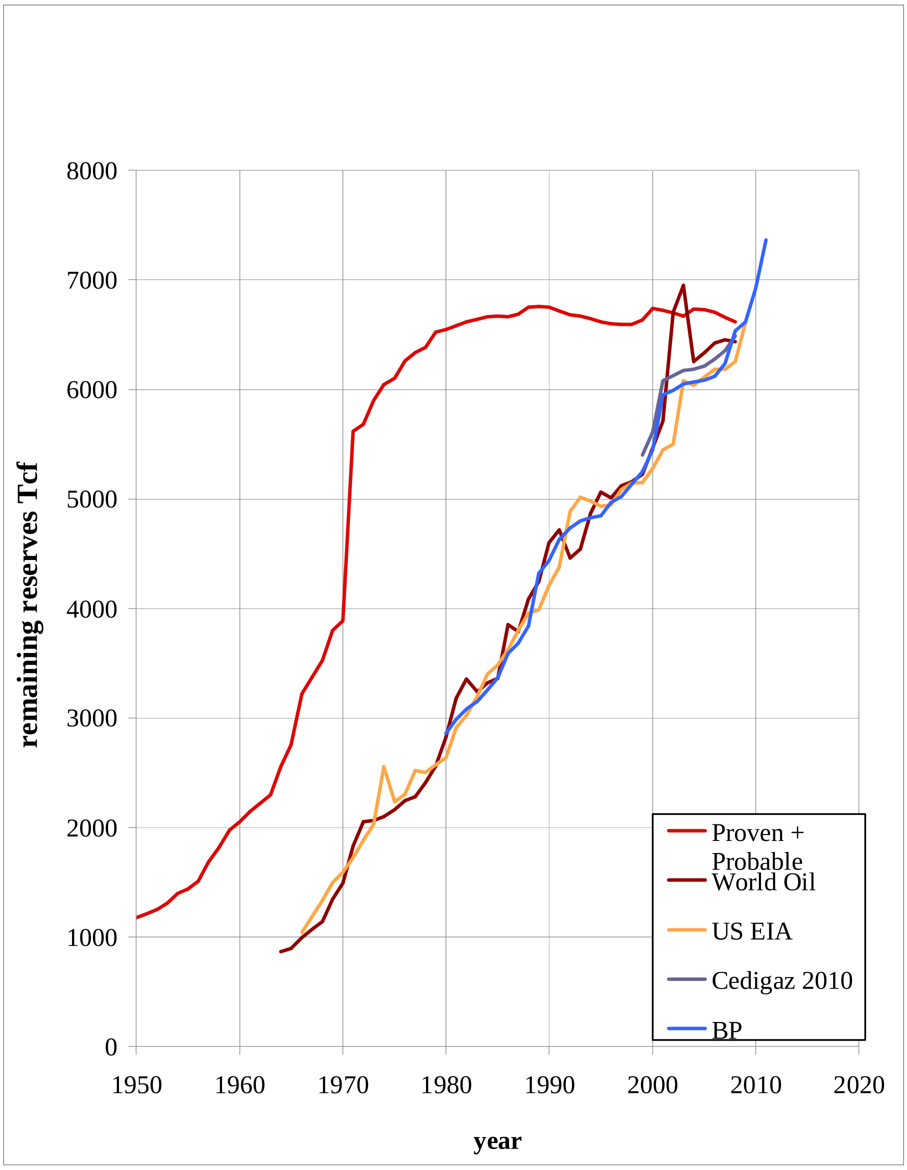

Figure 21: World remaining conventional gas reserves from proven sources and from proven plus probable (in red) sources. Most recent results from BP show an increase in gas reserves due to unconventional sources.[339]

b) The world reserve/production ratio is declining

In 2010, the BP Statistical Review on World Energy reported a 7.3% increase in natural gas production worldwide – the largest increase since 1984; at the same time, consumption also increased by 7.4%.[340] This rise in both production and consumption has resulted in a decrease in the reserve/production ratio – the number of years supply left at current consumption levels – and the general trend shows an ongoing decline since the 1980s. In 2010, world proved natural gas reserves were sufficient to meet 59.6 years of global production:

[339] Jean Laherrère, *Future of natural gas supply* (May 2004) <http://www.peakoil.net/JL/JeanL.html> Updated data supplied by Jean Laherrère and BP *Statistical review* 2012

[340] BP, *Statistical Review* (2011) p. 4

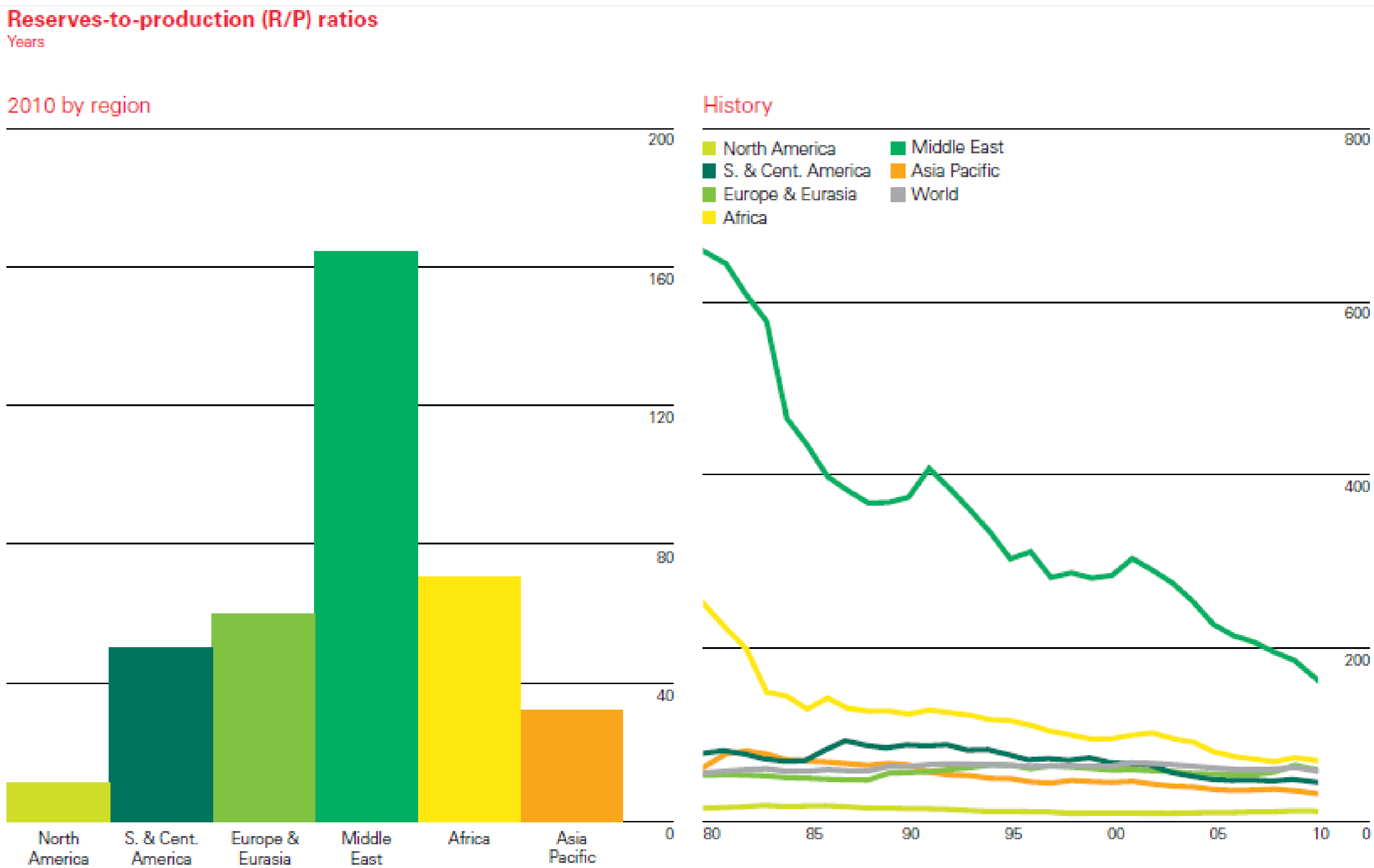

Figure 22: Natural Gas reserves-to-production (R/P) ratios 2010[341]

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[341] In ibid p. 7

However, with demand projected to significantly increase over the coming years, as much as 50% by 2035 according to the IMF's World Economic Outlook Special Report on the "Golden Age of Gas"[342], the declining trend of this ratio is likely to accelerate significantly.

c) Growing interest in Natural Gas as a more 'environmentally friendly' substitute for oil and coal will see consumption rates rise, speeding up the depletion rate

Carbon reduction measures have seen growing interest in natural gas – the 'cleaner' of the fossil fuels in terms of greenhouse gas emissions. The fuel has been held up as a 'bridge' to a low-carbon future – an intermediary catalyst for the transition to a non-fossil fuel based economy in varying degrees.[343] As a result demand is likely to increase even faster than currently experienced. If in 2010 there was 63 years of supply left[344], an annual increase of demand of 2% (bearing in mind that the historical trend is 2.6% per year)[345], provides 42 years of supply, and with a 4% annual demand increase, the supply falls to 33 years worth.

d) Our ability to meet projected demand and production rates, both physically and technically, is highly questionable

Meeting this growing demand will require production to expand to quantities much greater than today – indeed, annual gas production must increase by three times the current production of Russia, the second greatest producer of natural gas in the world, to meet the 50% increase by 2035.[346] Most outlooks generally project that natural gas production to 2030 will need to grow faster than it has historically, ranging from 400 billion to 500 billion cubic feet per day.

Do these reserves exist? As with oil, natural gas reserve figures are clouded in uncertainty and contention. Many reports speak of "abundant" global natural gas supplies. But we need to be careful to distinguish between 'resource' estimates (the total and finite amount of the material found in the earth's crust), 'recoverable resource' estimates (the subset of the total resource that can be produced and converted into fuel not currently considered commercial at the time of estimation) and 'reserve' estimates (that resource which is discovered, recoverable, commercial and remaining). For example, an MIT study on 'The Future of Natural Gas', explains that the current mean projection of remaining recoverable resource is

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342 International Energy Agency, 'Are we entering a golden age of gas? Special Report', *World Energy Outlook 2011* (2011) <http://www.iea.org/weo/docs/weo2011/WEO2011_GoldenAgeofGasReport.pdf> [accessed March 2012]

343 Stephen P.A. Brown, Alan J. Krupnick, and Margaret A. Walls, 'Natural Gas: A Bridge to a Low-Carbon Future', *Resources for the Future* (December 2009) <http://www.ocgi.okstate.edu/OREC/NAT_GAS.pdf> [accessed March 2012] and Massachusetts Institute of Technology, *The Future of Natural Gas* (25 June 2010) <http://web.mit.edu/press/2010/natural-gas.html> [accessed March 2012]

344 BP, *Statistical Review of World Energy*, (2010) <http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf> [accessed March 2012]

345 National Petroleum Council, *Hard Truths: Facing the Hard Truths about Energy* (July 2007) <http://downloadcenter.connectlive.com/events/npc071807/pdf-downloads/NPC_Facing_Hard_Truths.pdf> [accessed March 2012] p. 29

346 International Energy Agency, 'Are we entering a golden age of gas?', *World Energy Outlook 2011* (2011)

16,200 Trillion cubic feet (Tcf), 150 times current annual global gas consumption, with low and high projections of 12,400 Tcf and 20,800 Tcf, respectively.[347] However, the report goes onto explain that of this mean projection, approximately 9,000 Tcf could be economically developed with a gas price at or below $4/Million British thermal units (MMBtu) at the export point – that is around just under half of the recoverable resource can be considered as 'reserves', or commercially recoverable today (at the 2011 average price for gas).[348]

A US National Petroleum Council (NPC) report 'Facing Hard Truths' explains the range of estimates for reserves and points up the discrepancy of basing future production trends on this level of uncertainty.[349] Depending on which data-set is used alters the perspective on what is possible significantly. The report explains that about 3,000 Tcf of natural gas has already been produced.[350] The projected supply of natural gas to 2030 ranges from 3,100 to 3,650 Tcf, which at mid-range estimates of conventional, global, technically recoverable resources are considerably greater than combined historical and projected production, for example representing around 50% of USGS-estimated conventional gas reserves.[351] The report concludes that "Whether or not global natural gas production reaches a plateau during the study time frame, the possibility becomes greater within the next 50 years, unless a major technical breakthrough allows economic production of significant volumes of unconventional gas and gas hydrates."[352] Similarly, the IEA, admit in their "Golden Age of Gas" model that although "There is potential to increase gas production in all regions and thereby enhance overall energy security…realising this potential is not assured."[353]

e) **Restricted access and geographical spread increases resource limitations**

Another barrier to exploitation of recoverable reserves is restricted access and the concentrated geographical spread of resources globally. Nearly two-thirds of natural gas resources are concentrated in four countries, Russia, Qatar, Iran, and Saudi Arabia, which are projected to show the biggest growth in future production.[354]

Indeed, the largest production increases from 2008 – 2035 are projected for the Middle East and non-OECD Asia regions, according to the EIA's 2011 International Energy Outlook:

[347] Massachusetts Institute of Technology, *The Future of Natural Gas: An Interdisciplinary MIT Study* (2010) <http://web.mit.edu/mitei/research/studies/report-natural-gas.pdf> [accessed March 2012] p. XII
[348] Ibid p. XII
[349] National Petroleum Council, *Hard Truths* (July 2007)
[350] Ibid p. 132
[351] Ibid
[352] Ibid p. 132
[353] IEA, 'Are we entering a golden age of gas?', *World Energy Outlook 2011* (2011) p. 42
[354] Ibid p. 105

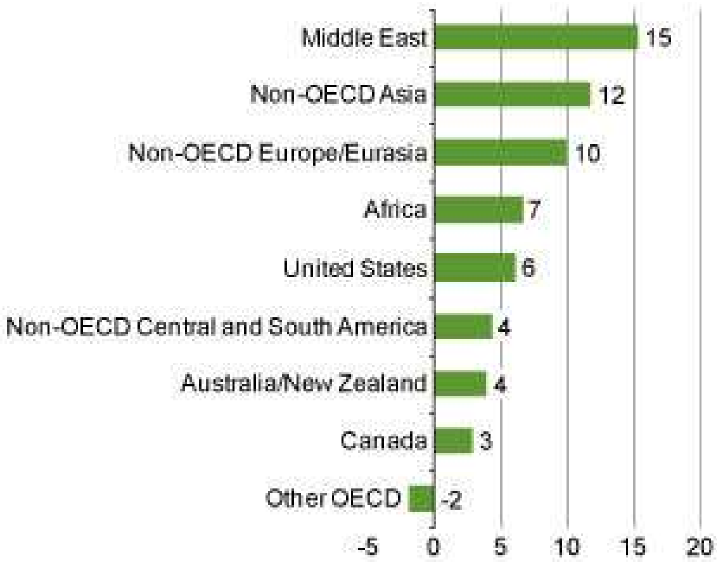

Figure 23: Change in world natural gas production by region (trillion cubic feet), 2008 - 2035[355]

Since these countries are relatively distant from likely consuming regions, it is anticipated that global gas supply chains will need to develop to connect producers and markets—similar to the trading system that has been developed over decades for oil. However, natural gas, unlike oil, faces several obstacles to transportation, which means that markets tend to be very regional and local. Pipelines are expensive and often hampered by geographic and political obstacles. Liquified natural gas is highly transportable but there are a limited number of ports and ships currently available. Developing a more mature and sophisticated international market for natural gas trade will require significant investment, international cooperation and time. The IEA "Golden Age of Gas" model states that long-lead times on infrastructure projects are a major obstacle to developing increased supply chains in the near-term future. Indeed, the IEA project that by 2015 global supply capacity of marketed gas could not exceed 132 Tcf and by 2020, this is likely only to rise to 146 Tcf.[356] Beyond that time, capacity increase will be based on the industry's confidence in prospects for future demand growth.

A further access issue relates to land ownership and regulatory frameworks. A 2007 NPC study on global access to oil and gas resources found that urban growth, competing land uses, and changing public values have placed ever increasing constraints on existing and new oil and gas development, particularly within the US, where as a result, up to 97% of oil (20 BBbls) and 87% of natural gas (162 Tcf) resources beneath federal lands onshore in the United States have significant access restrictions.[357]

The report also finds a shifting demographic towards more state-owned, or National Oil Companies (NOCs). In the 1960s, 85% of global oil and gas reserves were reportedly fully open to International Oil Companies (IOCs).[358] Today, between 60 to nearly 80% of world

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[355] In U.S Energy Information Administration, *International Energy Outlook 2011* (19 September 2011) <http://www.eia.gov/forecasts/ieo/nat_gas.cfm> [accessed March 2012]
[356] IEA, 'Are we entering a golden age of gas?', *World Energy Outlook 2011* (2011) p.55
[357] NPC, 'Global Access to Oil and Gas', *Working document of the NPC Global Oil and Gas study* (18 July 2007) <http://www.npc.org/study_topic_papers/7-stg-globalaccess.pdf> [accessed March 2012] p. 1
[358] Ibid p. 9

proved oil reserves are now in countries that have NOCs or have established substantial restrictions on foreign investment and activity in the oil and gas energy sector.[359] As a result, the report concludes that this decreasing access to world oil and gas reserves has "impaired the ability of IOCs to replace reserves."[360]

f) Unconventional gas exploitation is uncertain, expensive and often un-economic

Most recently, the growth in reserve figures, particularly in North America, has mostly come from 'unconventional' sources which are much more difficult to extract, requiring intensive energy throughput, advanced technical recovery infrastructure and increasingly remote access (see box opposite[361]). A 2009 article in The Telegraph quoted BP's Chief Executive, Tony Hayward, attributing rising reserves at that time to these developments alone.[362] The IMF's WEO "Golden Age of Gas" scenario projects that unconventional gas could account for 24% of global gas supplies by 2035, an increase from 12% in 2008, and make up more than 40% of the total increase in demand until then.[363] But it admits that this will only be possible with the right investment, policy framework and continued technical development.

[359] Ibid

[360] Ibid

[361] US annual consumption in 2011 of natural gas is over 24 trillion cubic feet (Tcf) per year (http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm). There are 317 Tcf of proven gas reserves in the US (http://www.eia.gov/naturalgas/crudeoilreserves/) of which 97 tcf was shale (30% increase over previous year). The Potential Gas Committee, a nonprofit organisation of volunteer members who work in the natural gas exploration, production and transportation industries estimated total reserves in 2009 of 1,836 Tcf of natural gas (American Petroleum Institute: facts about shale gas http://www.api.org/policy-and-issues/policy-items/exploration/facts_about_shale_gas.aspx). Halliburton in 2008 estimated reserves of 1000 Tcf (Halliburton - US shale gas White paper 2008). The US Energy Information Administration (EIA) estimates the technically recoverable reserves of shale gas each year (not proven) however these figures vary greatly from year to year. In 2011 the estimate was 827 Tcf (23.4 trillion cubic metres) from 353 Tcf estimated in 2010. However the 2012 estimate was revised downwards to 482 Tcf. The main reason for these widely differing estimates is due to new techniques making previously inaccessible gas available, better data as more shale formations are measured (rather than estimated), steeper declines in field productivity than expected and more accessible information. For example, in 2012 the U.S. Energy Department cut its estimate for natural gas reserves in the Marcellus shale formation from 410 Tcf to 141 Tcf citing improved data on drilling and production (Bloomberg, 23 January 2012).

[362] Ambrose Evans-Pritchard, 'Energy crisis is postponed as new gas rescues the world', *The Telegraph* (6 February 2012) <http://www.telegraph.co.uk/finance/comment/ambroseevans_pritchard/6299291/Energy-crisis-is-postponed-as-new-gas-rescues-the-world.html> [accessed March 2012]

[363] IEA, 'Are we entering a golden age of gas?', *World Energy Outlook 2011* (2011)

Fracking: a US solution?

Over the past few decades hydraulic fracturing ('fracking') has been used to access natural gas stored in shale. Fracking involves injecting liquid into shale to break up formations and release the trapped gas. The US started to use fracking techniques over 40 years ago and natural gas extracted in this way now accounts for around 30% of production.

Natural gas prices in the US were fairly stable from the mid-1980s until the turn of the century when they started to rise and become more volatile (US Energy Information Administration). Following peaks in gas prices between 2005 and 2008, increased investment into unconventional reserves led to large increase in domestic availability. Gas prices have now fallen again. The availability of domestic natural gas provides the US with the ability to insulate itself from global resource constraints. However, how much shale gas is available is uncertain. Current proven reserves of shale gas give the US an additional 4 years of domestic consumption based on current usage. Estimated resources extend this up to 80 years however when unproven resources have been measured they are often revised downwards sharply and the most recent US EIA projections allow for an additional 20 years of domestic gas supply based on current usage. Of course if the availability of cheaper gas in the short term results in increased usage then the projection of available years will only shorten.

Globally fracking still remains in its infancy and figures for the availability of unconventional natural gas vary greatly. The environmental impact, including the energy required to extract this type of gas and therefore the greenhouse gas footprint as well as the local water usage (and possible political response to these), also remains uncertain.

Similarly, a 2011 report by the US National Petroleum Council sums up the paradox in its title – "Prudent Development - Realizing the Potential of North America's Abundant Natural Gas and Oil Resources".[364] The report concludes that resources are there, but require the right regulatory and investment framework to be exploited to their full potential. As is already the case, "the dominant source of U.S. and Canadian natural gas production in the near, medium- and long- terms is likely to be onshore unconventional gas, such as tight gas, shale gas, and coalbed methane".[365]

Outside of Canada and the U.S., there has been very little development of the unconventional gas supply base, although there is much interest. Developing this in regions where the infrastructure and technology for this kind of extraction do not yet exist, in so-called "virgin" areas, is extremely costly both in terms of upfront capital investment and pay-back time.[366] The environmental impact and possible link between fracking and earthquakes may limit their developments. The relative expense of unconventional sources, compared

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[364] NPC, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources* (15 September 2011) <http://www.npc.org/Prudent_Development.html> [accessed March 2012]

[365] Ibid pp. 1-10

[366] IEA, 'Are we entering a golden age of gas?', *World Energy Outlook 2011* (2011) p.53

with conventional in terms of both production and transportation costs, are shown in this IEA graph:

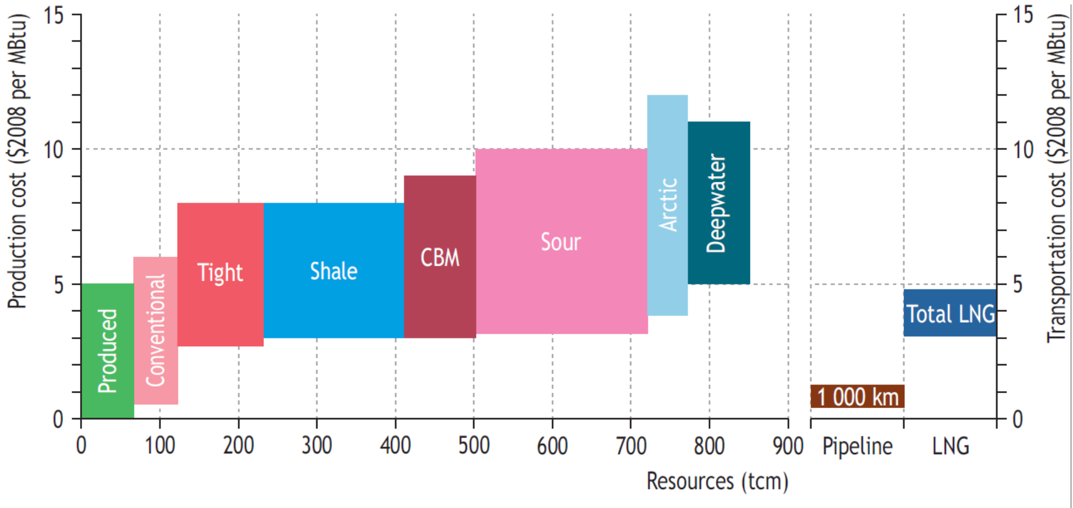

Figure 24: Long-term gas supply cost curve[367]

4.3.2 When will the constraint occur?

Peak predictions for natural gas are relatively sparse in the literature, compared with oil. The following table shows the most recent estimations from a few different sources:

	World Peak Estimate	Source	Date of prediction
Before 2012	2008/9	Bakhtiari (Retired Senior Advisor for the Iranian National Oil Company)[368]	2006
By 2020	N/A	N/A	N/A
By 2030	2027	Hughes (Canadian hydrocarbon geologist)[369]	2009
	2030	Laherrère (Petroleum engineer and consultant; member of the Association for the Study of Peak Oil & Gas)[370]	2004
After 2030	Around 2040	Li (University of Utah)[371]	2011
No peak on the horizon	N/A		

[367] In IEA, *World Energy Outlook 2009,* (2009), <http://www.iea.org/textbase/nppdf/free/2009/weo2009.pdf>[accessed March 2012] p. 416 (Reproduced with permission.)
[368] *Forward Thinking: Macquarie Advisor Services Magazine*, Vol. 3 (2006) <http://www.macquarie.com.au/retail/acrobat/forward_thinking_q3_magazine.pdf> [accessed March 2012]
[369] Chris Turner, 'An Inconvenient Talk', *The Walrus* (June 2009) <http://www.walrusmagazine.com/articles/2009.06-energy-an-inconvenient-talk//?ref=2009.07-environment-an-inconvenient-talk> [accessed March 2012]
[370] Jean Laherrère, *Future of natural gas supply* (May 2004)
[371] Dr Minqi Li, *Peak Energy and the limits to global economic growth* (University of Utah, July 2011)

4.4 Uranium

4.4.1 What is the evidence for a resource constraint?

According to Cameco, one of the world's largest uranium producers, and based on 2008 World Nuclear Association data, production from world uranium mines supplies 67% of the requirements of global nuclear power utilities.[372] The rest (33%) comes from secondary sources, or inventories held by utilities, other fuel cycle companies and governments, as well as recycled materials from military nuclear programmes, used and reprocessed reactor fuel and uranium from depleted stockpiles. John Busby, an energy analyst associate for UK-based Sanders Research and author of a report entitled 'After Oil', lays out the supply-demand situation based on 2008/9 World Nuclear Association figures in the table below:

Table: Uranium demand, mining production and deficit in tonnes[373]

Country	**Uranium required 2011 (WNA)**[(5)]	**% of world demand**	**Indigenous mining production 2010 (WNA)**[(6)]	**Deficit**
USA	18,376	29	1,660	16,716
France	9,254	15	0	9,254
Japan	2,805	4 (NB: Significant reduction since Fukushima)	0	2,805
Russia	4,912	8	3,562	1,350
Germany	1,934	3	0	1,934
South Korea	4,029	6	0	4,029
UK	2,093	3	0	2,093
Ukraine	2,288	3	860	1,428
Canada	1,845	3	9,783	-7,938 Surplus
Spain	1,379	2	0	1,379
Sweden	1,366	2	0	1,366
Rest of world	12,271	20		
Total	62,552	100	53,663	8,669 (14%)

The table shows that the world was in a 14% deficit in 2010 – the percentage supplied by secondary sources. This gap between supply and demand is not a new phenomenon. The World Nuclear Association reveals that the world has been in uranium ore deficit since the mid-1980s, when the shortfall of supplies for civil power started to be made up by the higher production into military inventories during the Cold War years, as depicted in the graph below:

372 'Uranium 101: Markets', *Cameco* (March 2010) <http://www.cameco.com/uranium_101/markets/> [accessed March 2012]

373 In John Busby, 'Why Nuclear is not a sustainable source of low carbon energy', *After Oil* (17 January 2012) <http://www.after-oil.co.uk/nuclear.htm> [accessed March 2012] (Reproduced with permission.)

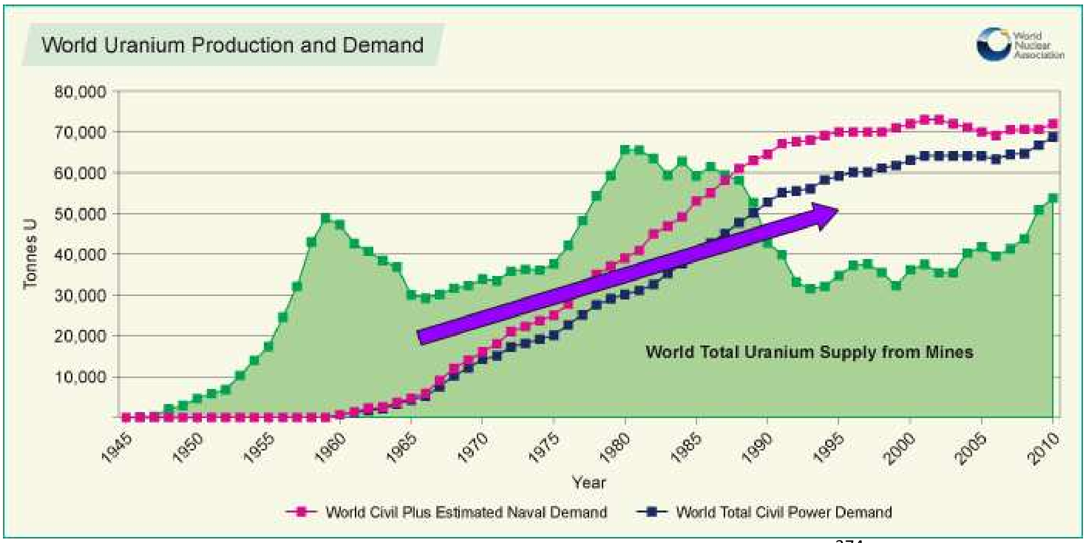

Figure 25: World uranium production and demand[374]

Demand is projected to increase by 33% according to the World Nuclear Association's reference scenario between 2010 – 2020 alone, corresponding to a 27% increase in nuclear reactor capacity.[375] The WNA warns that in this reference case, supply will fail to meet demand as soon as the mid-2020s – much sooner (2015) if its demand projections increase to its upper scenario[376] – unless primary production increases[377]:

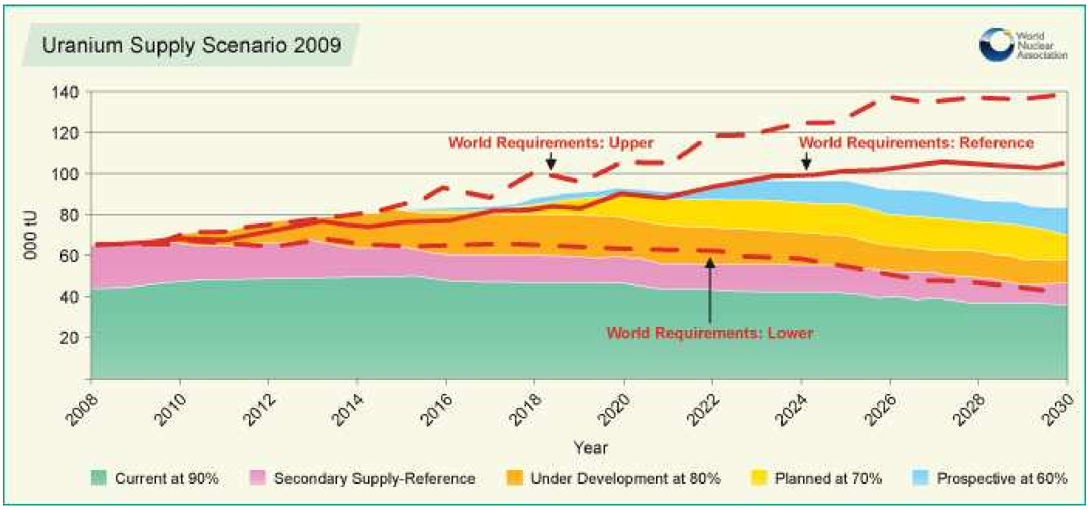

Figure 26: Uranium supply scenario 2009[378]

374 In World Nuclear Association, *World Uranium Mining* (December 2011) <http://www.world-nuclear.org/info/inf23.html> [accessed March 2012] (Reproduced with permission.)
375 World Nuclear Association, Uranium Markets (July 2010) <http://www.world-nuclear.org/info/inf22.html> [accessed March 2012] (Reproduced with permission.)
376 Ibid
377 'More U mines needed as nuclear grows', *World Nuclear News* (10 Sept 2010) <http://www.world-nuclear-news.org/ENF_More_U_mines_needed_as_nuclear_grows_1009091.html> [accessed March 2012]
378 In World Nuclear Organization, *Uranium Markets* (July 2010) <http://world-nuclear.org/info/inf22.html> [accessed March 2012]

Primary production *has* increased over the past three years – by 25% - thanks to a higher uranium price.[379] WNA estimates for future consumption could be on the conservative side, with one Australian academic predicting that uranium demand will quadruple by 2040, due to the rising demand coming from China and India in particular.[380] However, it remains unclear if this projected demand will continue over the long-term following the Fukushima nuclear accident. Although, recent reports indicate that confidence is increasing and the disaster will not sway Asian plans to boost their nuclear capacity.[381]

a) Supply is constrained by current known reserves:

There is disagreement about reserve estimates and figures. The Energy Watch Group looks at known amounts with suitable ore as reported by the Red Book of the NEA and plots the following likely production pattern graph based on three different reserve estimates:

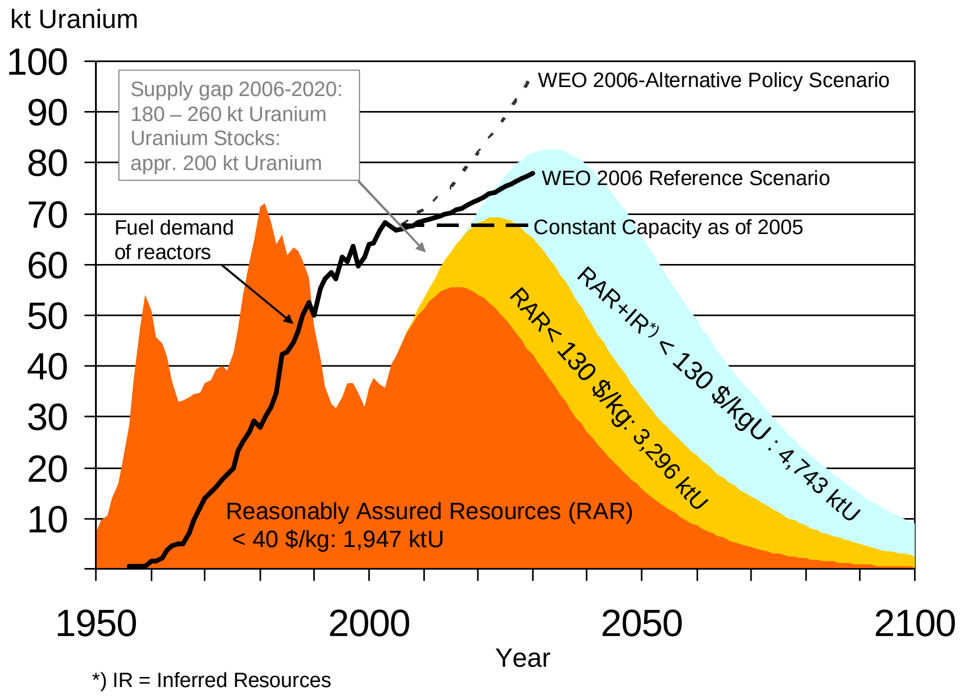

Figure 27: History and forecast of uranium production based on reported resources. *(The smallest area covers 1900 kt uranium which has the status of proved reserves while the data uncertainty increases towards the largest area which is based on possible reserves consisting of 4700 kt uranium.)*[382]

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[379] *Metals Economics Group Strategic Report: Uranium Supply Pipeline*, 2010 (2010) <http://www.metalseconomics.com/pdf/Uranium%20Supply%20Pipeline%202010.pdf> [accessed March 2012]

[380] Jonathan Faurie, 'Global consumption of uruanium to quadruple over next 30 years', *Mining Weekly* (26 March 2010) <http://www.miningweekly.com/article/uranium-demand-to-increase-four-times-over-the-next-30-years-2010-03-19> [accessed March 2012]

[381] Julia Gordon, 'Uranium industry warms up after Fukushima', (Reuters), *Mineweb.com* (7 March 2012) <http://www.mineweb.com/mineweb/view/mineweb/en/page72103?oid=146870&sn=Detail> [accessed March 2012]

[382] In Energy Watch Group, Uranium Resources and Nuclear Energy (December 2006) <http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Uranium_3-12-2006ms.pdf> [accessed March 2012] (Reproduced with permission.)

The dark orange band represents 'reasonably assured resources' (RAR) economically mined for $40/kg or less. The lighter orange band represents those minable at $130/kg or less. The current spot price is around $110/kg[383], so between these two tiers. The light blue band represents 'inferred resources' – or those not yet found, but thought to exist somewhere in the Earth's crust. On top of this, future demand projections of reactors are plotted based on IEA WEO 2006 scenarios, with the result that a supply gap is illustrated between 2006 – 2020, even when including the inferred band.

In 2001, the IAEA also conducted an 'Analysis of Uranium Supply to 2050', similarly showing a peak and decline of supply based on extraction of all available resources – both high and low cost.[384] Their analysis shows a peak occurring in 2024, if highest cost resources are included, with a peak occurring sooner if this does not occur:

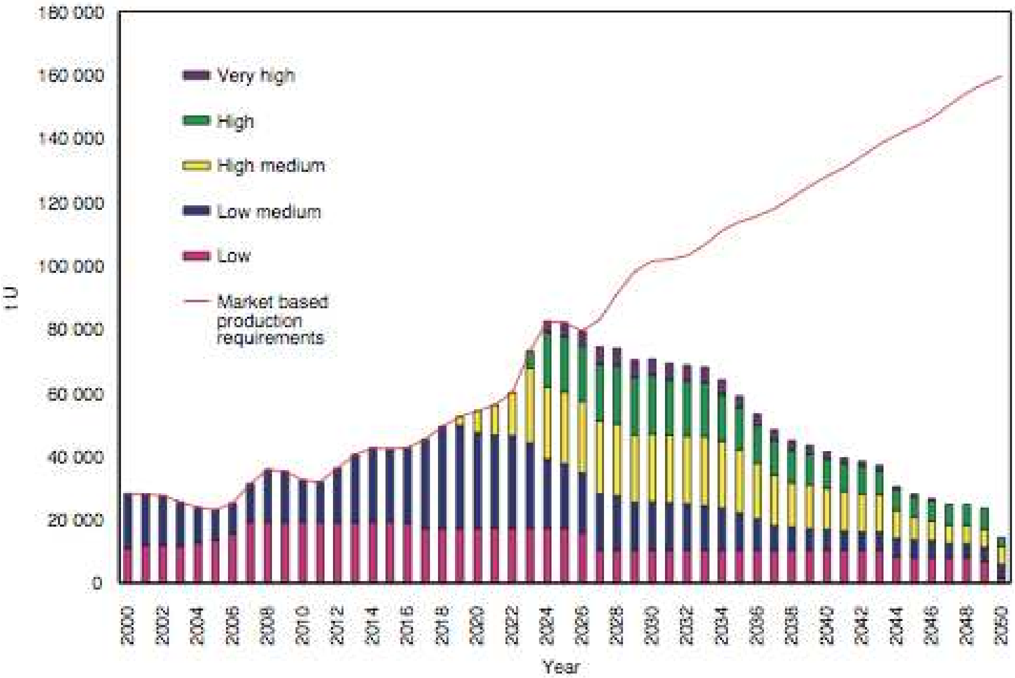

Figure 28: Projection of market based production from study RAR by cost category - middle demand case.[385]

In the 2008 report 'Supply of Uranium', updated in 2011, the World Nuclear Assocation is very optimistic about future supply stating that the "Limits to Growth fallacy" takes no account of economic considerations and long-term supply analysis.[386] However, the 2009 report on '*The Global Nuclear Fuel Market Supply and Demand 2009 – 2030*' stated that primary uranium production must increase dramatically from current levels to meet demand.[387]

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[383] *Uranium Miner* <http://www.uraniumminer.net/market_price.htm> [accessed March 2012]
[384] International Atomic Energy Agency, *Analysis of Uranium Supply to 2050*, (Vienna: IAEA, May 2001) <http://www-pub.iaea.org/MTCD/publications/PDF/Pub1104_scr.pdf> [accessed March 2012]
[385] In ibid p. 39 (Reproduced with permission.)
[386] World Nuclear Association, *Supply of Uranium* (September 2011) <http://www.world-nuclear.org/info/inf75.html> [accessed March 2012]
[387] 'More U mines needed as nuclear grows', *World Nuclear News* (10 September 2010)

While the accuracy of these reserve figures is not certain, the general picture painted by these various institutions points to a similar conclusion – a peak in production is on the horizon, especially if new reserves are not found, if secondary sources require replacing and if demand is set to increase.

b) Secondary supplies are drying up and will soon run out

Relying on continued supply into the future from secondary sources, which for the past 10 – 15 years have supplied fuel to a third of the world's nuclear reactors,[388] is not possible. Cameco has said that, with the exception of recycled material, secondary supplies are finite and will be depleted over the next few years.[389] In particular, the US-Russia Highly-Enriched-Uranium (HEU) agreement in which Russia has been supplying uranium to the western market through a programme of dismantling a significant proportion of its nuclear weaponry, is due to come to an end in 2013.[390] Russia holds the world's largest stock of HEU, the majority of which is in its military stockpile. The expiry of the HEU agreement is estimated to result in a decrease of supply in secondary uranium sources from 20,000 MTU to 12,000 MTU per year between 2010 and 2013.[391] However, according to the Nuclear Engineering International magazine, even these forecasts are quite uncertain as they assume continuing availability to the commercial market.[392]

The end of the Russian programme is likely to coincide with a general end to secondary supply sources in the near-term. A 2009 study by Michael Dittmar from the Institute of Particle Physics in Switzerland based on data from the IAEA/NEA 2007 Red Book, "Uranium Resources, Production and Demand", and from the World Nuclear Association (WNA) states that due to an almost unavoidable yearly drawdown of 10,000 tonnes from worldwide civilian uranium stocks (which totalled roughly 50,000 tonnes in that year) civilian stocks will be essentially exhausted by 2015.[393] It concludes that "all data indicate that a uranium supply shortage in many OECD countries can only be avoided if the remaining military uranium stocks from Russia and the USA, estimated to be roughly 500,000 tons are made available to the other countries", which it deems strategically unlikely.[394]

In a 2008 press statement launching the 2007 edition of the Red Book, the leading resource on global uranium production, the IAEA and the NEA also express concern over the current unsustainability of the nuclear fuel situation: "Most secondary resources are now in decline and the gap will increasingly need to be closed by new production. Given the long lead time typically required to bring new resources into production, uranium supply shortfalls could develop if production facilities are not implemented in a timely manner."[395]

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[388] Michael Dittmar, *The Future of Nuclear Energy: Facts and Fiction* (21 August 2009) <http://arxiv.org/PS_cache/arxiv/pdf/0908/0908.3075v1.pdf> [accessed March 2012]
[389] 'Uranium 101: Markets', *Cameco* (March 2010) <http://www.cameco.com/uranium_101/markets/#two> [accessed March 2012]
[390] Ibid
[391] Michael H. Schwartz and Julian Steyn, 'New Capacity Needed', *Nuclear Engineering International* (October 2010) <http://www.neimagazine.com/story.asp?storyCode=2057706> [accessed March 2012]
[392] Ibid
[393] Michael Dittmar, *The Future of Nuclear Energy: Facts and Fiction* (21 August 2009)
[394] Ibid p. 1
[395] Nuclear Energy Agency, *Uranium resources sufficient to meet projected nuclear energy requirements long into the future* (3 June 2008) <http://www.oecd-nea.org/press/2008/2008-02.html> [accessed March 2012]

c) Supplies of high-quality uranium ore have been steadily declining

According to environmental engineers from Monash University in Australia, on average, supplies of high-quality uranium ore have been steadily declining worldwide for the past 50 years, and are likely to continue to permanently decline in the mid- to long-term.[396] For example, the average country ore grade for the United States in the 1990s was typically 0.07 – 0.11% U_3O_8, which is about one-third of that in the late 1950s of 0.28% U_3O_8.[397] Their 2008 study, which examined a range of data on uranium mining and milling, found that Canada is the only country which has seen a substantive rise in its average ore grade. However, this has not significantly affected typical global average ore grade, which has remained at between 0.05 and 0.13% U_3O_8 over the past five decades, even considering incomplete production and likely grades in remaining countries.[398] The below graph depicts this trend (updated from the 2009 report):

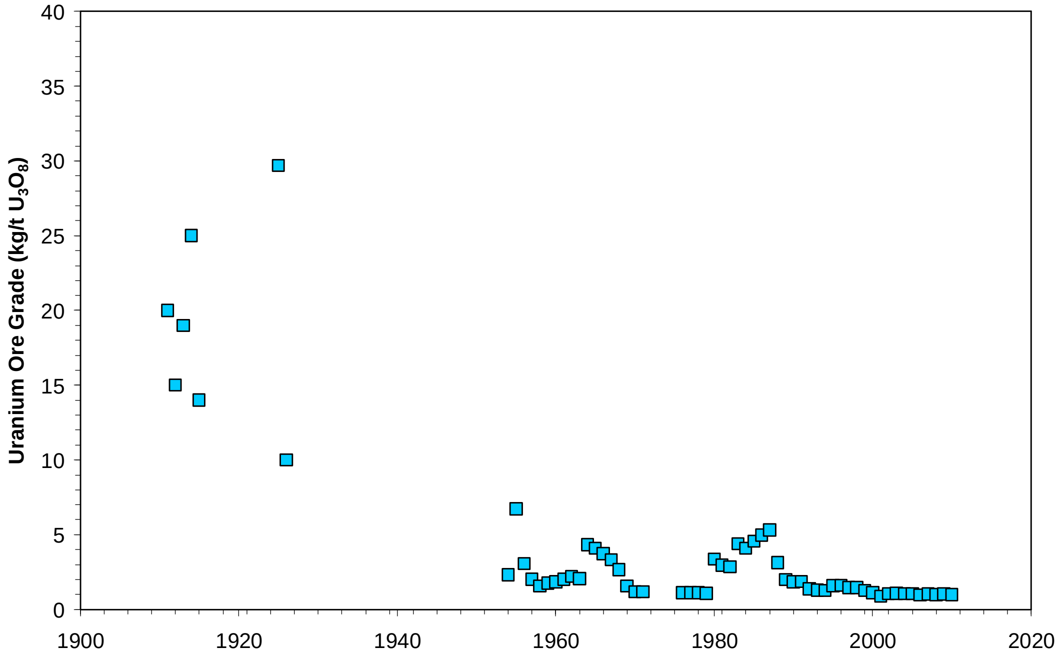

Figure 29: Uranium ore grade over time[399]

The Energy Watch Group, in conducting similar research, found that Canada, with 9% of the world's known uranium resources, is the only country in the world with a reasonable amount of uranium with an ore grade larger than 1%.[400] About 90% of world wide resources

[396] Charles Q. Choi, 'Uranium Supply Decline Clouds Nuclear Power's Future', *Live Science* (22 April 2008) <http://www.livescience.com/2463-uranium-supply-decline-clouds-nuclear-power-future.html> [accessed March 2012]

[397] Ibid

[398] Dr Gavin M. Mudd and Mark Diesendorf, 'Sustainability of Uranium Mining and Milling: Toward Quantifying Resources and Eco-Efficiency', *Environmental Science and Technology*, Vol.42, No. 7 (2008) <http://pubs.acs.org/doi/pdfplus/10.1021/es702249v> [accessed March 2012] pp.2624 - 2630

[399] In Dr Gavin M. Mudd, *The Sustainability of Mining in Australia : Key Production Trends and Their Environmental Implications for the Future* (Monash University, 2009)<http://users.monash.edu.au/~gmudd/files/SustMining-Aust-Report-2009-Master.pdf> [accessed March 2012] (Reproduced with permission).

[400] Energy Watch Group, Uranium Resources and Nuclear Energy (December 2006) <http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Uranium_3-12-2006ms.pdf> [accessed March 2012]

have ore grades below 1%; more than two-thirds of which is below 0.1%.[401] Australia has the largest deposits of world resources (31%), 90% of which have an ore grade of less than 0.06%.[402] Similarly, Kazakhstan has 12% of world resources (the second largest deposit), but most of this contains a uranium ore concentration far below 0.1%.[403] Ore grade substantially determines how easily uranium can be mined. The lower the grade, the more energy is demanded to extract the uranium content. The report finds that energy required to extract and process ore at concentrations below 0.01 – 0.02% is so high that the Energy Returned on Energy Invested is less than one, making it economically unviable.[404] However, there is contention on this issue as to the point at which the EROEI makes mining ore economically unfeasible.[405]

d) The discovery rate is on a long-term declining trend

According to the Monash University study, despite broad-ranging exploration in Australia in the 1970s which turned up spectacular results, there have only been two new economic deposits discovered since 1975: Kintyre, described as 'modest', in 1985 and Beverley 4 Mile in 2002, although here an economic mineral resource was not confirmed until early 2007.[406] The study states that all increases in uranium resources between 1985 – 2005 were a result of increased drilling and new assessments at known deposits, rather than any new discoveries. They conclude that this pattern of no 'world-class' discoveries, those greater than 50kt U_3O_8, over the past 20 years is thought to be similar in other countries. Although the authors admit that possible further discoveries could still occur, they foresee that these are likely to be in successively deeper mines, which require more energy to extract, and of lower ore quality, following the long-term declining trend of average country ore grades.[407]

A presentation on discovery rates given by MinEx Consulting firm to the AMIRA International 8th Exploration Managers Conference in 2010, finds that discoveries of uranium deposits have been steadily declining over the past few decades as a result of the existing search space becoming depleted. This is shown by each wave of discovery since the 1940s becoming ever smaller, and even as exploration expenditure has increased:

[401] Ibid
[402] Ibid
[403] Ibid
[404] Ibid
[405] David Fleming, *The Lean Guide to Nuclear Energy: A Life Cycle in Trouble* (The Lean Economy Connection: London, 2007) <http://www.theleaneconomyconnection.net/nuclear/Nuclear.pdf> [accessed March 2012]
[406] Dr Gavin M. Mudd and Mark Diesendorf, 'Sustainability of Uranium Mining and Milling', *Environmental Science and Technology*, (2008) p. 2629
[407] Gavin M. Mudd and Mark Diesendorf, 'Sustainability of Uranium Mining and Milling', *Environmental Science and Technology* (2008)

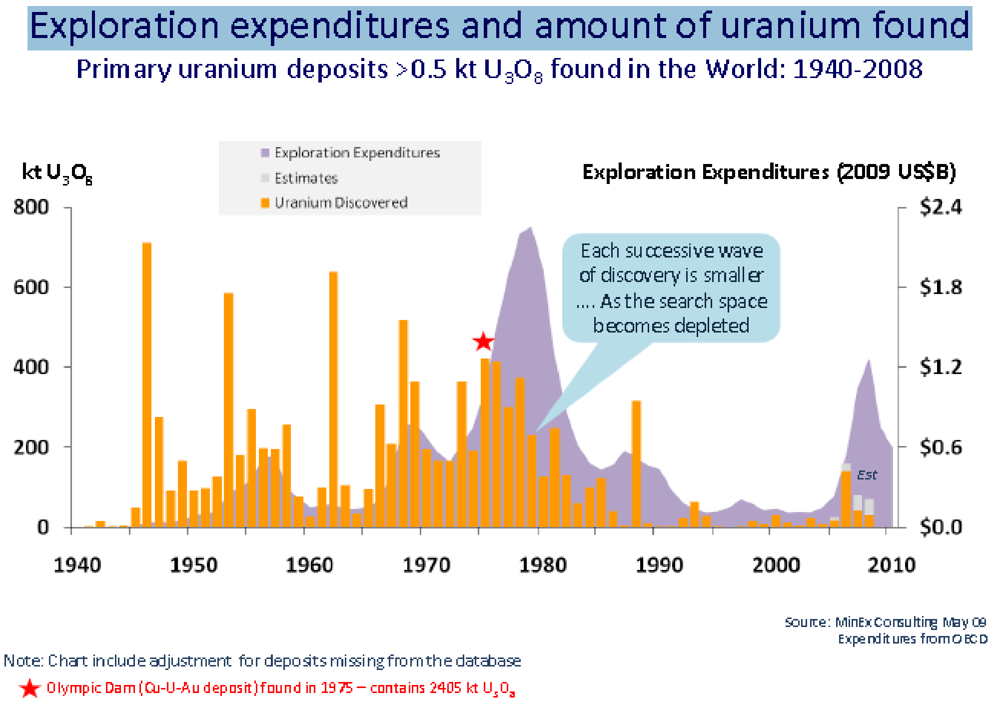

Figure 30: Exploration expenditure and amount of uranium found[408]

As a result, uranium discovery costs per pound discovered have quadrupled over the past 40 years: in the Western world:

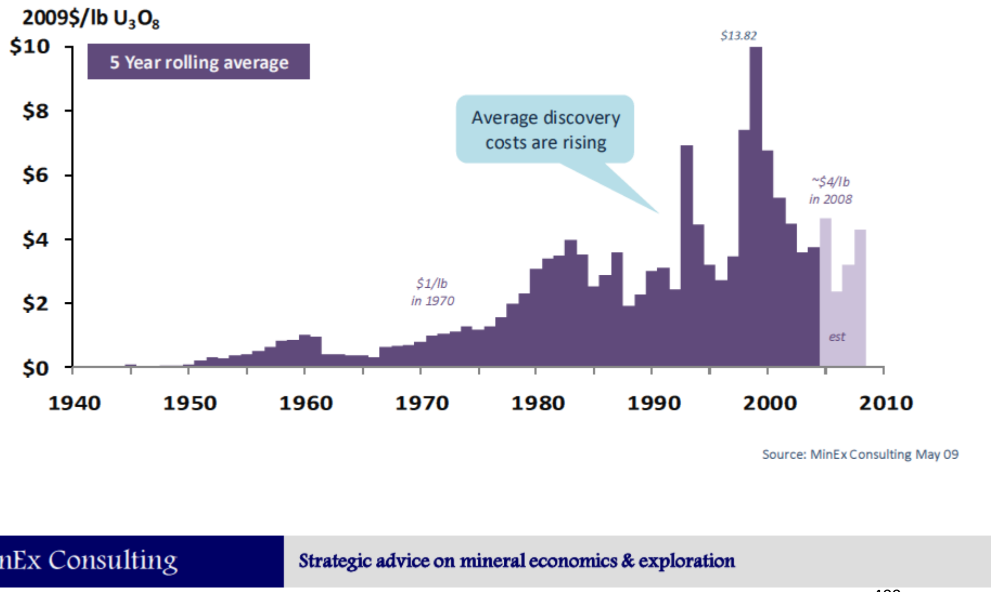

Figure 31: Increase in uranium discovery costs over the last 40 years[409]

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[408] In Richard Schodde (MinEx Consulting), "The Declining Discovery Rate – What is the Real Story?", Presentation to the AMIRA International's Exploration Managers Conference, Yarra Valley, Victoria (March 2010) <http://www.minexconsulting.com/publications/Declining%20Discovery%20Rates%20-%20the%20Real%20Story%20-%20AMIRA%20Conference%20March%202010.pdf> [accessed March 2012]

[409] In ibid

4.4.2 When will the constraint occur?

	World Peak Estimate	Source	Date of prediction
Before 2012	1980 – but supplies still abundant	Vance (NEA)[410]	2006
	Supply shortages 2010 – 2019	Fleming (The Lean Economy Connection)[411]	2007
By 2020	2015	Dittmar (Institute of Particle Physics)[412]	2011
By 2030	N/A		
After 2030	2034 (high-grade ore)	Storm van Leeuwen (Cedeeta Consulting)[413]	2006
	2035 (at current consumption rates)	Energy Watch Group[414]	2006
No peak on the horizon	At current consumption, enough to last 100 years	OECD[415]	2007
	Up to 1000 years supply available – potentially limitless	Hopf (US Nuclear Engineer)[416]	2004

[410] Robert Vance, 'What can 40 years of Red Books tell us?', Nuclear Development Division, Nuclear Energy Agency, OECD, Paper in the 'Building Nuclear Futures: Challenges and Opportunities' series, (2006) <http://www.world-nuclear.org/sym/2006/pdf/vance.pdf> [accessed March 2012]
[411] David Fleming, *The Lean Guide to Nuclear Energy* (The Lean Economy Connection: London, 2007)
[412] Michael Dittmar, *The End of Cheap Uranium* (17 June 2011) <http://arxiv.org/PS_cache/arxiv/pdf/1106/1106.3617v2.pdf> [accessed March 2012]
[413] International Atomic Energy Agency, *Uranium 2007: Resources Production and Demand* (OECD Publishing: June 2008) <http://www.oecdbookshop.org/oecd/display.asp?sf1=identifiers&st1=9789264047662> [accessed March 2012]
[414] Energy Watch Group, Uranium Resources and Nuclear Energy (December 2006) <http://www.energywatchgroup.org/fileadmin/global/pdf/EWG_Report_Uranium_3-12-2006ms.pdf> [accessed March 2012]
[415] International Atomic Energy Agency, *Uranium 2007: Resources Production and Demand* (June 2008)
[416] James Hopf, 'World Uranium Reserves', *American Energy Independence* (November 2004) <http://www.americanenergyindependence.com/uranium.aspx> [accessed March 2012]

4.5 Land, Soil & Food

4.5.1 What is the evidence for a resource constraint?

a) Availability of new arable land is limited and productivity growth is slowing

The growth in human population from 3 billion to 6.8 billion over the past 40 years or so has largely been made possible by advances in crop and livestock production achieved by intensification (increased use of fertiliser, pesticide and irrigation) rather than extensification (land use change to agriculture).[417] Indeed, between 1961 and 2006, while the global population increased by 114%, the total amount of arable land (the land upon which cereals are grown, excluding lower-quality grazing land), increased globally by only 10.2% from 1.282 billion hectares to 1.411 billion hectares.[418] This has resulted in a halving of arable land available per person on the planet – 0.22 hectares per person in 2006 compared with 0.42 ha in 1961:

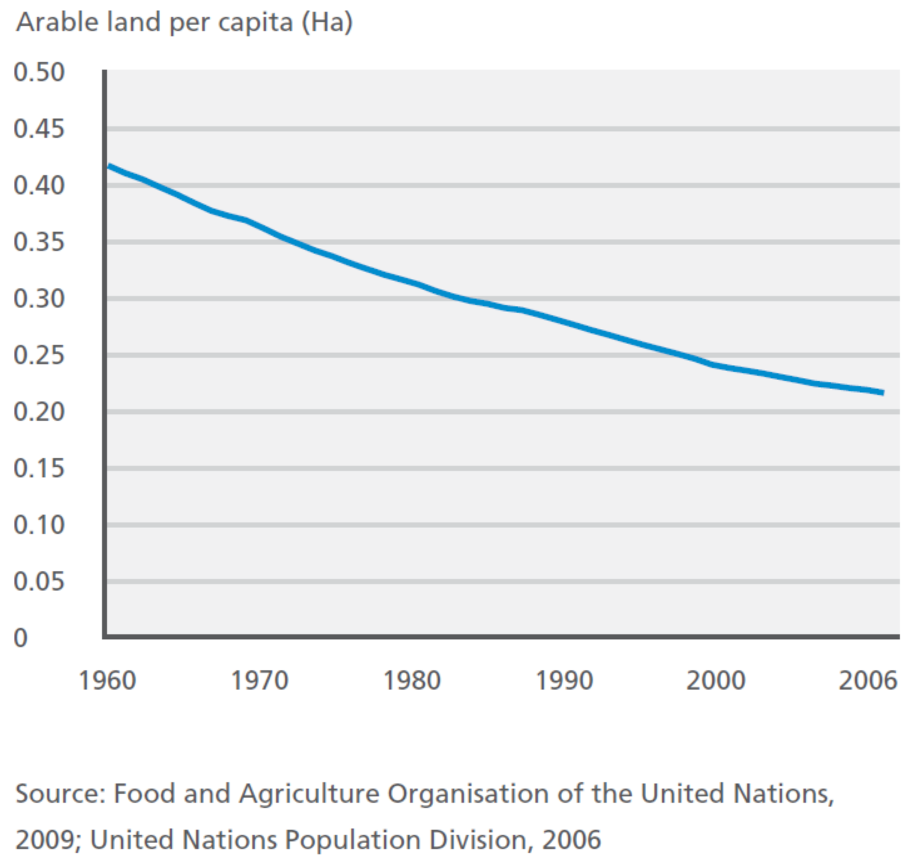

Figure 32: Trends in per capita availability of arable land between 1961 and 2006[419]

[417] Pete Smith et al., 'Competition for Land', *Philosophical Transactions of the Royal Society*, Vol. 365, No. 1554 (27 September 2010) <http://rstb.royalsocietypublishing.org/content/365/1554/2941.full> [accessed March 2012] pp. 2941-2957
[418] Ibid
[419] In Land Commodities, *The Land Commodities Global Agriculture & Farmland Investment Report 2009: A Mid-Term Outlook* (2009)

However, over the same time there was a 2.7-fold increase in cereal yields, 1.6-fold increase for tubers and roots, and a 4-fold increase for meat.[420] According to the United Nations Environment Programme, over the period 1965 – 2008 efficiency and productivity gains from increased use of fertiliser contributed 50% to yield growth and irrigation added a further 20% to world crop production, whereas increased usage of cropland and rangeland area was much less of a factor in boosting world production during that time, as the below graph shows:[421]

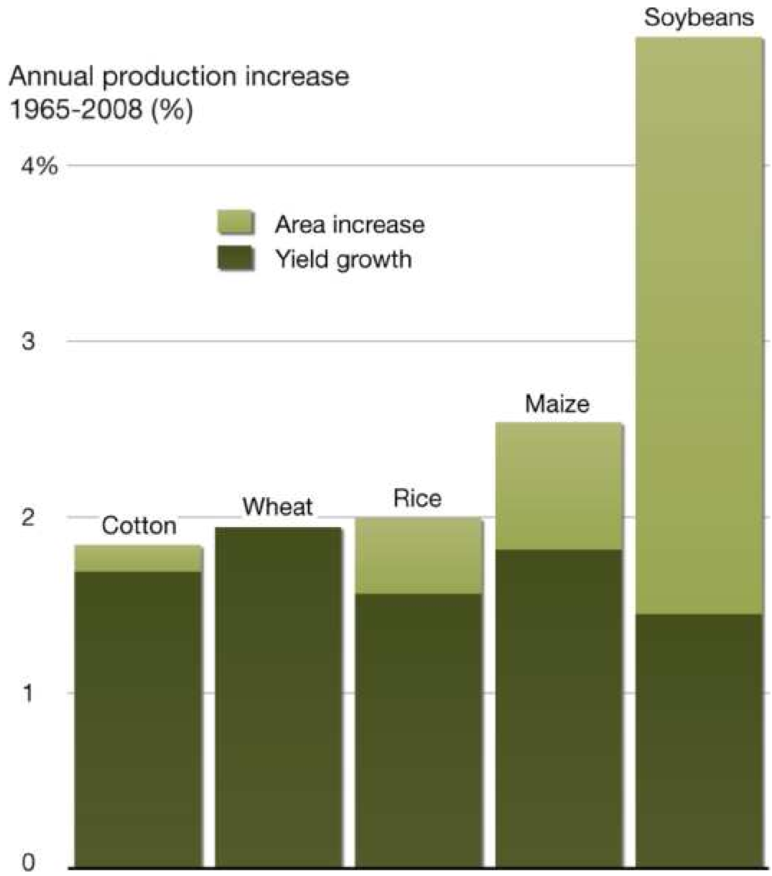

Figure 33: Agricultural production increases, per commodity 1965-2008[422]

Had this yield increase over the last 40–50 years not been achieved, almost three times more land would have been required to produce crops to sustain the present population.[423] With productivity growth in high-input agriculture slowing down and increasing concern

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<http://www.landcommodities.com/assets/pdfs/Land_Commodities_Farmland_Investment_Report.pdf> [accessed March 2012] p. 22 (Reproduced with permission.)

[420] Pete Smith et al., 'Competition for Land', *Philosophical Transactions of the Royal Society* (September 2010)

[421] Christian Nellemen et al. (eds.), *The Environmental Food Crisis – The environment's role in adverting future food crises,* United Nations Environment Programme Rapid Response Assessment, UNEP/GRID-Arendal, (February 2009), <http://www.grida.no/files/publications/FoodCrisis_lores.pdf> [accessed March 2012] p. 20

[422] In ibid

[423] Pete Smith et al., 'Competition for Land', *Philosophical Transactions of the Royal Society* (September 2010)

over related negative environmental impacts[424], the UN warns that future yield increases to meet projected future demand of a 9-billion strong global population (anticipated to be between a 70 – 100% increase on current demand[425]) will likely rely more heavily on cropland expansion rather than productivity gains, but at the expense of biodiversity[426]. Where area increase *has* been a major factor in increased global food production – for soybean production in particular as shown in the graph above – this has already come at the expense of biodiversity and forest conservation mostly in the Amazon. Considering both productivity decline and global demand projections, is there any cultivatable land still available for sustainable expansion?

In December 2005, scientists from the University of Wisconsin-Madison combined satellite land cover images with agricultural census data from every country in the world to create detailed maps of global land use.[427] They found that in the year 2000, 40% of the earth's land surface was already being used for agricultural production. In 1700 only 7% of the world's surface was used in this way.

In addition, a critical component for agricultural productivity is the availability of fertilizer which depends heavily on the availability of nitrogen and phosphates. Although a recent literature review by the International Fertiliser Development Centre (2010) concluded that we have more phosphate reserves than previously indicated (60,000 Mt as opposed to previous USGS calculations of 16,000 Mt), the Global Phosphorous Research Initiative released a statement which highlighted that this may well buy more time, but that major concerns around 'peak phosphorous' still hold.[428] One of these is the declining ore grade quality of phosphate rock. Remaining reserves are generally of lower quality requiring greater energy and economic inputs to extract.

According to a study published in the journal *Global Environmental Change* in May 2009, while demand for phosphorous, used primarily in fertiliser, is expected to grow by 50 – 100% by 2050, production is expected to peak by 2030, with the quality and cost of remaining resources becoming less attractive.[429] The World Phosphate Institute states that 70- 75% of phosphate rock production is also concentrated in only 4 countries: the USA, China, Morocco and Russia.[430] The environmental impact of large scale use of fertilisers is also coming under increasing focus (see section 4.8.1).

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424 United Nations, *Land: Access to and distribution of agricultural land* (2008) <http://www.un.org/esa/sustdev/publications/trends2008/land.pdf> [accessed March 2012]

425 University of Minnesota, 'New projection shows global food demand doubling by 2050', *ScienceDaily* (21 November 2011) <http://www.sciencedaily.com/releases/2011/11/111121194043.htm> [accessed March 2012]

426 Christian Nellemann et al. (eds.), *Environmental Food Crisis: The Environment's Role in Averting Future Food Crises*, A UNEP rapid response assessment, United Nations Environment Programme/GRID Arendal (February 2009), p.22

427 Kate Ravilious, 'Food crisis feared as fertile land runs out', *The Guardian* (6 December 2005), <http://www.guardian.co.uk/science/2005/dec/06/agriculture.food> [accessed March 2012]

428 Global Phosphorus Research Initiative, *GPRI Statement on Global Phosphorus Scarcity* (2 September 2010) <http://phosphorusfutures.net/files/GPRI_Statement_responseIFDC_final.pdf> [accessed March 2012]

429 Dana Cordell, Jan-Olof Drangert and Stuart White, 'The story of phosphorus: Global food security and food for thought', *Science Direct* (11 February 2009) <http://www.sciencedirect.com/science/article/pii/S095937800800099X> [accessed March 2012]

430 L. Cisse and T. Mrabet, 'World Phosphate Production: Overview and Prospects', *Phosphorus Research Bulletin*, Vol. 15 (2004) <http://www.imphos.org/download/jena/cisse_prb-15.pdf> [accessed March 2012] pp. 21-25

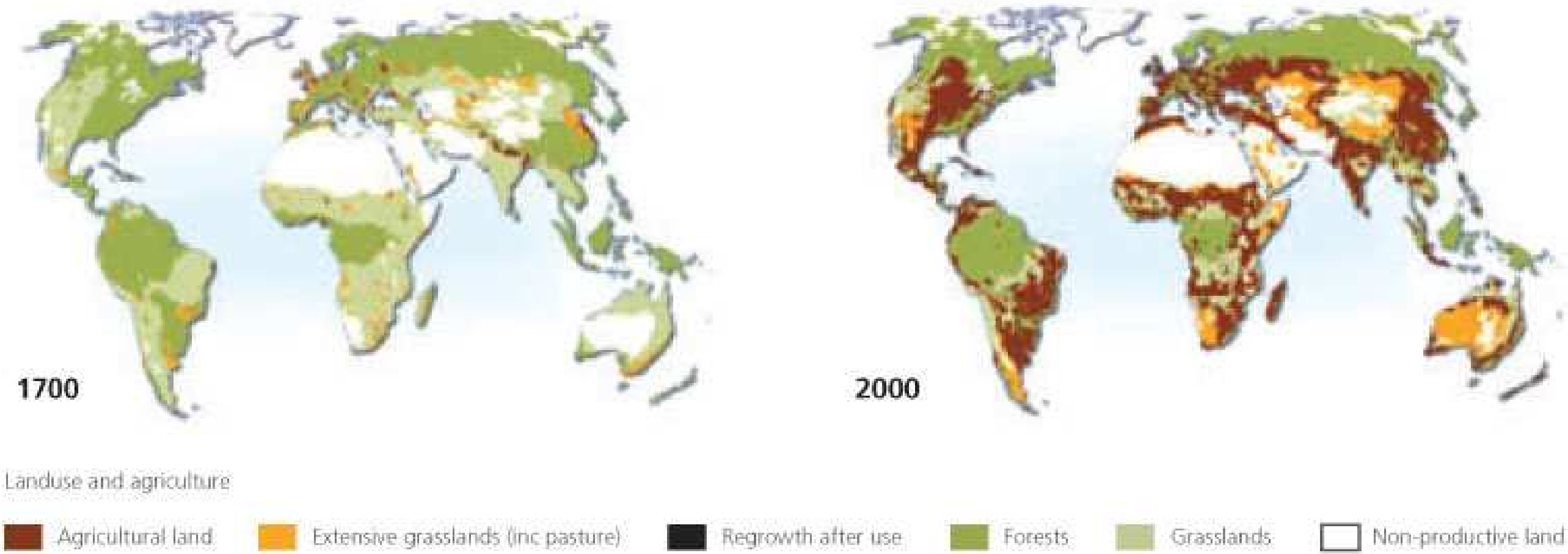

Figure 34: Estimated global agricultural land use 1700 and Actual global agricultural land use in 2000 based on satellite imagery[431]

[431] In Land Commodities, *The Land Commodities Global Agriculture & Farmland Investment Report 2009*, (2009) p. 69

Their research pointed to the conclusion that room for further agricultural expansion is now strictly limited and that the best fertile lands have already been used. "Except for Latin America and Africa, all the places in the world where we could grow crops are already being cultivated. The remaining places are either too cold or too dry to grow crops,"[432] said Dr Navin Ramankutty from the research team. The result is that there is concern that rising demand for food will simply cause increasing soil erosion, deforestation and water pollution as environmental pressure intensifies.

Similarly, a 2010 report on competition for land use finds that of the world's 13.4 billion ha land surface, about 3 billion ha is suitable for crop production and about one-half of this is already cultivated (1.4 billion ha in 2008).[433] The other half is currently beneath tropical forests, thus the report states that converting this to agricultural land would have devastating effects on biodiversity conservation, greenhouse gas emissions, regional climate and hydrological changes, and requires costly infrastructural investment. However, in some regions, according to FAO data, expansion will be possible and likely – particularly in Latin America, Sub-Saharan Africa and the Caribbean, but in South and East Asia, and the Near East/North Africa, there is almost no land available for expansion.[434] Disagreement on land availability is based on technical constraints, socioeconomic conditions, macroeconomics, geophysical approaches, consideration of conservation and ecosystem requirements as well as competing pressures on land use, amongst other variables. Despite ongoing discussions, however, overall, it is clear competition for land is becoming stiffer, suggesting a global scarcity.

b) Competition over land use is increasing

World demand for agricultural commodities is rapidly expanding due to income growth and urbanisation trends. There is scope for improving the efficiency and lowering waste within the global food chain however overall demand will fast outstrip these gains. The International Food Policy Research Institute's projections until 2015 show that global cereal demand will increase across all regions as much as 20%.[435] By 2050, demand is expected to increase by more than one-third in East Asia and the Pacific and three-fold in Sub-Saharan Africa.[436] In China, most of the demand for cereals will be driven by animal feed demand, which will double by 2050.[437] These trends will be accompanied by strong growth in meat consumption, especially in poultry and beef. Poultry consumption per capita will increase almost three-fold by 2050, and beef consumption more than two-fold, along with a sharp rise in milk production.[438] These trends are in the context of declining rates of productivity improvement and increasing pressure of inputs (e.g. phosphates, land, soil). For example, according to the OECD, wheat yields have been growing slower than demand with gains from genetic modification reaching a plateau.[439] The IFPRI agree that overall present productivity

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[432] Kate Ravilious, 'Food crisis feared as fertile land runs out', *The Guardian* (6 December 2005)
[433] Pete Smith et al., 'Competition for Land', *Philosophical Transactions of the Royal Society* (September 2010)
[434] Ibid, p.2943
[435] Joachim von Braun, 'Supply and Demand of Agricultural Products and Inflation - How to Address the Acute and Long-Run Problem', IFPRI, Prepared for the China Development Forum, Beijing (22 – 24 March 2010)
<http://www.ifpri.org/sites/default/files/pubs/pubs/confpapers/20080322jvbchinaforum.pdf> [accessed March 2012]
[436] Ibid
[437] Ibid
[438] Ibid
[439] Gustavo A. Slafer, 'Challenges and Opportunities for Further Improvements in Wheat Yield', *OECD*

growth in agriculture is simply too low to cope with the fast demand due to land and water constraints and lack of investment.

According to a 2010 article in the *Science* journal bringing new land into cultivation may be possible but competition for land from other human activities makes this an increasingly unlikely and costly solution, particularly if protecting biodiversity and the public goods provided by natural ecosystems (for example, carbon storage in rainforest) are given higher priority.[440] An example of this in practice is the case of Palm Oil plantations. In April 2011 it was reported that the supply of land for planting in Indonesia and Malaysia, the world's biggest producers, is running out due in part to increasingly strict land expansion rules driven by concern over biodiversity and rainforest protection.[441] According to Kuala-Lumpur based analyst Ken Arieff Wong, land supply for palm oil plantation could run out by 2020 in Indonesia and 2022 in Malaysia as a result.[442] The *Science* article states that in addition to these pressures, loss of productive agricultural land to urbanisation, desertification, salinisation, soil erosion and other unsustainable land management practices is likely to be exacerbated by climate change and further compounded by growing competitive pressure from non-food crops, particularly biofuels. As a result of such competition, the study concludes that the most likely scenario is that more food will need to be produced from the same amount of (or even less) land to meet population-growth-induced demand increases.

A report in the journal *Food Policy* in 2010 agrees, advocating "sustainable intensification of cultivation" rather than "the continued expansion of cultivated area".[443] It sees the 21st Century as being unique in its intensification of competition for land due to what it calls the "food-energy-environment trilemma".[444] It cites increasing demand for energy and increasing demand for food as the two main drivers of exacerbated land use competition, which are compounded by growing concern over environmental impacts and greenhouse gas emission levels. Biofuels represent significant and controversial pressure on agricultural land use. Biofuel production since the 1990s has sharply increased:

iLibrary <http://www.oecd-ilibrary.org/agriculture-and-food/challenges-for-agricultural-research/challenges-and-opportunities-for-further-improvements-in-wheat-yield_9789264090101-14-en> [accessed March 2012] pp. 154-164

440 H. Charles J. Godfray et al., 'Food Security: The Challenge of Feeding 9 Billion People', *Science*, Vol. 327, No. 5967 (12 February 2010) <http://www.sciencemag.org/content/327/5967/812.full#aff-1> [accessed March 2012] pp. 812-818

441 Kevin Brown, 'Asian palm oil: limited supply', *Financial Times: Beyondbrics* Blog (18 April 2011) <http://blogs.ft.com/beyond-brics/2011/04/18/asian-palm-oil-limited-supply/#axzz1gnq0JUbG> [accessed March 2012], p. 1

442 Ibid

443 M., Harvey and S. Pilgrim, 'The new competition for land: Food, energy, and climate change', *Food Policy* (2010) <http://www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/science/11-576-sr34a-new-competition-for-land> [accessed March 2012]

444 Ibid

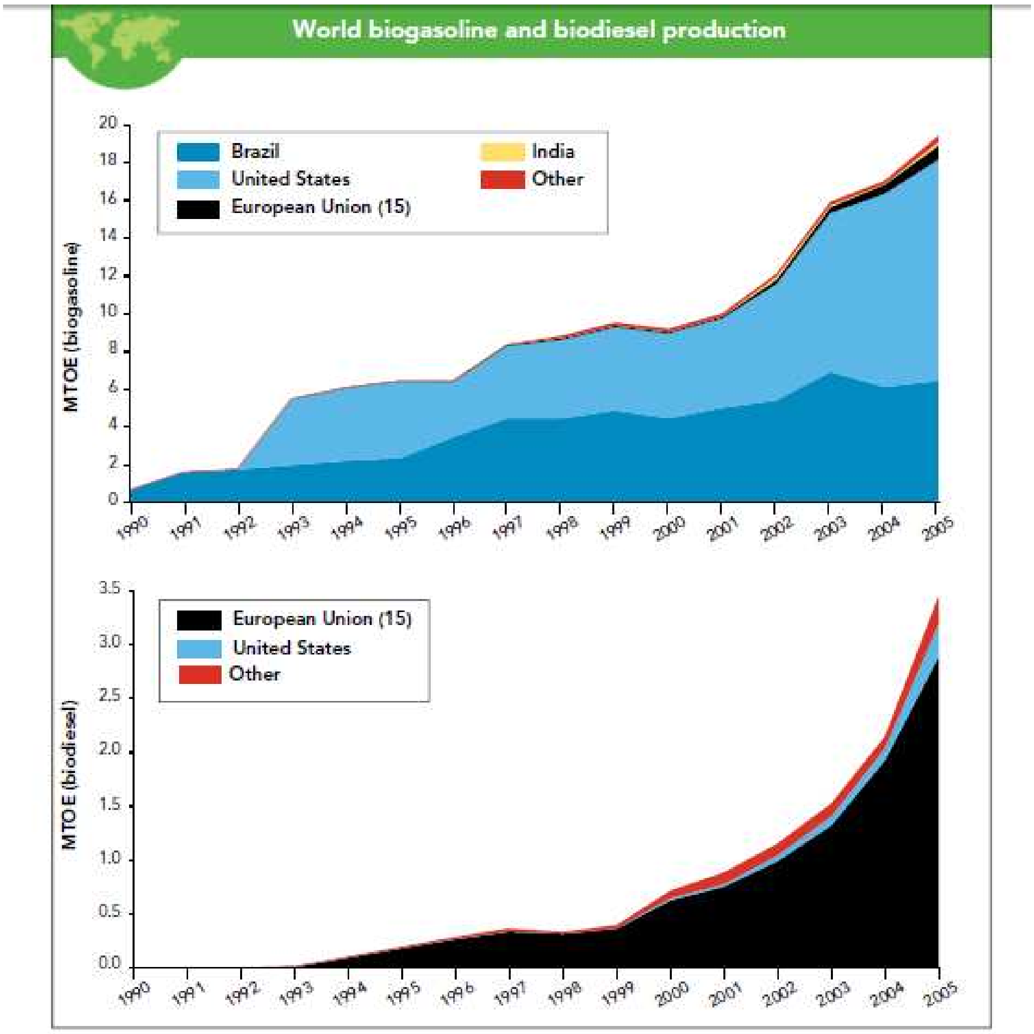

Figure 35: World biogasoline and biodiesel production[445]

To give a sense of the scale of competition going forward, a 2011 study conducted by academics from Imperial College London and the University of Bath, published in the journal *Food Policy*, found that estimates for land requirements for biofuels to meet 20–30% of the IEA predicted transport fuel demands to 2050, range from 100 million hectares, representing about 7% of current global arable cropland, up to about 650 million hectares, or about 45%.[446] The authors concluded that the low-end of requirements could be feasible if FAO estimations of potential available additional global cropland of up to 250 – 800 Mha are accurate, but that the high end estimates are "unfeasibly large" given global nutritional needs into the future.[447]

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[445] In United Nations Department of Economic and Social Affairs, Division for Sustainable Development, *Trends in Sustainable Development 2008-2009: Agriculture, rural development, land, desertification and drought,* (2008) <http://www.un.org/esa/sustdev/publications/trends2008/fullreport.pdf> [accessed March 2012], p. 22

[446] R. Murphy et al. 'Global developments in the competition for land from biofuels', *Food Policy* (2011) <http://www.bis.gov.uk/assets/bispartners/foresight/docs/food-and-farming/science/11-577-sr34b-global-developments-competition-land-from-biofuels> [accessed March 2012]

[447] Ibid, p. 8

Increased production of biofuels, and arising land use competition, has been attributed with causing as much as 70 – 75% of the food price spike in the late 2000s, highlighting the significance of the "trilemma" going forward.[448]

Demand for land to accommodate a growing urban population is increasing. The number of people living in urban areas is forecasted to increase from 2.9 billion people in 2000 to 5 billion people by 2030 and 6.4 billion by 2050.[449] As a result, the size of built-up areas will increase by 75% by 2030 and 225% by 2050.[450] China alone lost more than 14.5 million hectares of arable land (an area larger than England) to urbanisation between 1979 and 1995.[451]

c) Countries are purchasing large quantities of land overseas in a bid for national food and energy security

In September 2011, Oxfam reported that, based on data from the Land Matrix Partnership, a coalition of academic, research and non-governmental organisations, as much as 227 million hectares of land in developing countries – an area the size of Western Europe – has been sold, leased or is under negotiation since 2001, mostly to international investors and mostly since 2008.[452] Earlier that year, the World Bank placed the figure of "announced" deals before the end of 2009 at 56 million hectares, 70% of which was in Africa.[453] Other figures suggest 15 – 20 million hectares (International Food Policy Research Institute); another, 80 million (International Land Coalition).[454] What is clear is that the scale of this recent phenomenon, dubbed a modern-day 'land grab' by opponents, particularly when compared with an average annual expansion of global agricultural land of less than 4 million hectares before 2008, is unprecedented. A depiction of global land purchases based on data from the NGO Grain can be seen in the following figure from *The Guardian:*

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[448] Donald Mitchell, 'A Note on Rising Food Prices', *The World Bank Policy Research Working Paper 4682* (July 2008) <http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2008/07/28/000020439_20080728103002/Rendered/PDF/WP4682.pdf> [accessed March 2012]

[449] Land Commodities, *The Land Commodities Global Agriculture & Farmland Investment Report 2009*, (2009), p. 49

[450] Land Commodities, *Investors: Investment Fundamentals*, <http://www.landcommodities.com/index.cfm?fuseaction=main.dspInvestmentFundamentals> [accessed March 2012]

[451] Ibid

[452] Oxfam International, 'Land and Power: The growing scandal surrounding the new wave of investments in land', *Oxfam Briefing Paper* (151), *Oxfam GB* (22 Sep 2011) <http://policy-practice.oxfam.org.uk/publications/land-and-power-the-growing-scandal-surrounding-the-new-wave-of-investments-in-l-142858> [accessed March 2012]

[453] Klaus Deininger and Derek Byerlee et al., *Rising Global Interest in Farmland: Can it yield sustainable, equitable benefits?*, The World Bank, Agriculture and Rural Development 59463 (2011) <http://www-wds.worldbank.org/external/default/WDSContentServer/IW3P/IB/2011/02/08/000334955_20110208033706/Rendered/PDF/594630PUB0ID1810Box358282B01PUBLIC1.pdf> [accessed March 2012] p. XIV

[454] 'The surge in land deals: When others are grabbing their land', *The Economist* (5 May 2011) <http://www.economist.com/node/18648855> [accessed March 2012]

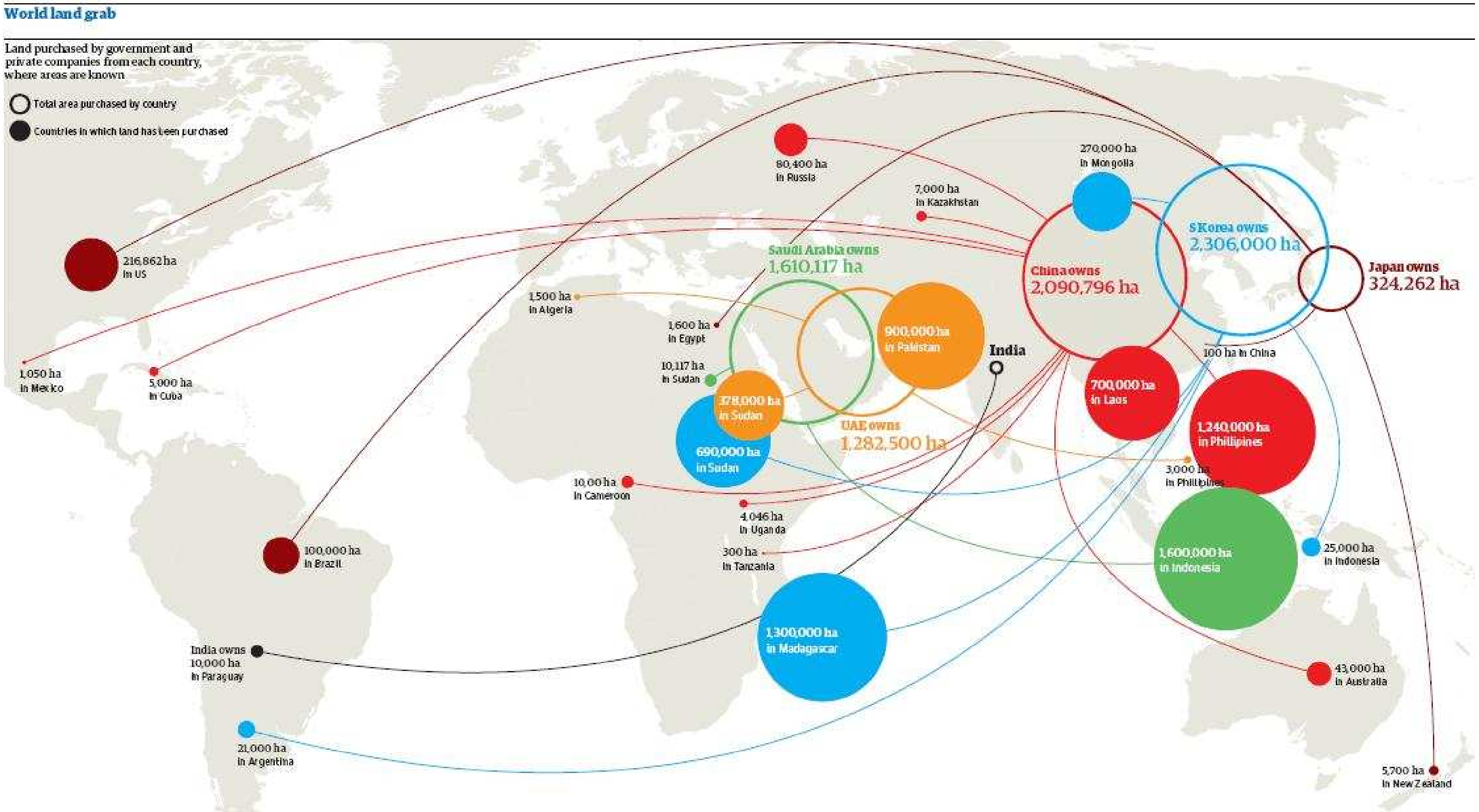

Figure 36: World land grab 2008[455]

[455] In 'World Land Grab', *The Guardian News & Media Ltd.,* (2008) <http://image.guardian.co.uk/sys-files/Guardian/documents/2008/11/21/LANDGRAB.pdf> [accessed March 2012] (Reproduced with permission.)

The impetus for these purchases are widely discussed. Oxfam concludes that land scarcity for agricultural production combined with volatile food prices on the world market are causing wealthy food-importing nations in particular to buy up land overseas in a bid for national food security.[456] The International Food Policy Research Institute agrees, adding that "increased pressures on natural resources, water scarcity, export restrictions imposed by major producers when food prices were high, and growing distrust in the functioning of regional and global markets have pushed countries short in land and water to find alternative means of producing food."[457]

The Gulf States, rich in capital but poor in land and water resources, as well as burgeoning economies and populations, China, India and South Korea, concerned about food security, are leading the race to secure foreign land acquisitions. The drive is also spurred on by desires for energy security, with interest in growing biofuel crops also prominent. In addition to the new scale of this phenomenon, another major change in trend is the players involved. While in the past most investment has been from the private sector, currently government-to-government deals are dominating, suggesting that worries over land scarcity, and food price volatility, are becoming more prominent in considerations of national security.[458] As Lennart Bage, President of the UN fund for agriculture and development said, fertile land has seemingly become a "strategic asset" on a par with oil.[459]

Competition for water (see section 4.6) is also critical. With 40% of the world grain harvest coming from irrigated land, water shortages and food shortages are closely intertwined. Indeed, a number of sources have described the recent growth in international land purchases as a competition for water access, rather than for land itself, with the most aggressive investors those that are facing significant water shortages already.[460]

Saudi Arabia is a case in point, being the first country to publicly acknowledge how water shortages are impacting grain harvests. After more than 20 years of wheat self-sufficiency, the Kingdom announced in January 2008 that its principle aquifer was largely depleted and it would therefore phase out wheat production up until 2016, when Saudi wheat production would end.[461]

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[456] Oxfam International, 'Land and Power', *Oxfam GB* (22 Sep 2011)
[457] Joachim von Braun and Ruth Meinzen-Dick, '"Land Grabbing" by Foreign Investors in Developing Countries: Risks and Opportunities', *International Food Policy Research Institute - Policy Brief 13* (April 2009) <http://www.landcoalition.org/pdf/ifpri_land_grabbing_apr_09.pdf> [accessed March 2012] p1
[458] 'Buying farmland abroad: Outsourcing's third wave', *The Economist* (21 May 2009) <http://www.economist.com/node/13692889> [accessed March 2012]
[459] Chris Mayer, 'Cash in on the rush to secure quality farmland', *DailyWealth* newsletter in *Money Week* (22 September 2008) <http://www.moneyweek.com/investments/commodities/quality-farmland-is-a-fertile-investment-24628#> [accessed March 2012]
[460] Claire Provost, 'Africa's great 'water grab'', *The Guardian* (24 November 2011) <http://www.guardian.co.uk/global-development/poverty-matters/2011/nov/24/africa-water-grab-land-rights> [accessed March 2012]
[461] Lester R. Brown, 'Falling Water Tables and Shrinking Harvests', *World on the Edge* (Earth Policy Institute, 2011)

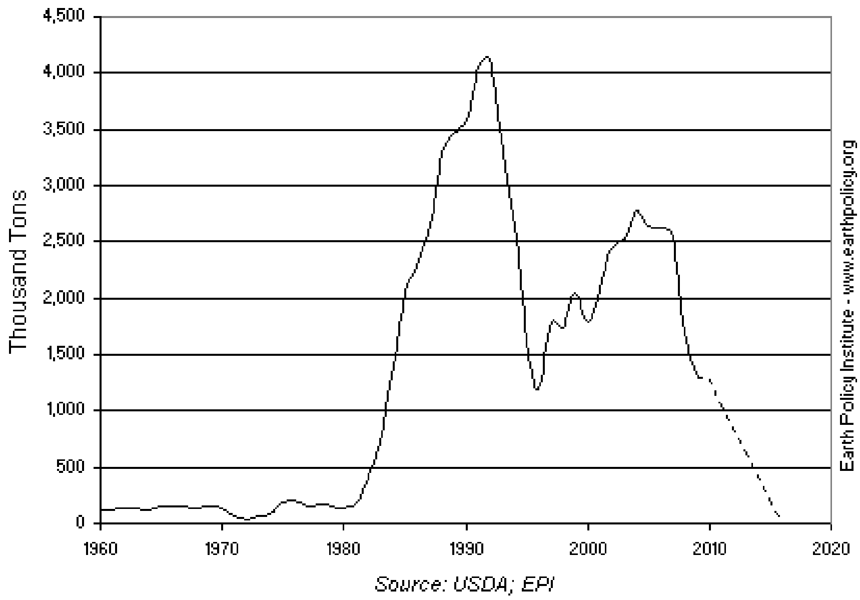

Figure 37: Wheat Production in Saudi Arabia, 1960 - 2009, with Projection to 2016[462]

As a result, Saudi Arabia has emerged as one of the leading buyers of international land, particularly in Africa. In 2008 the Saudi government earmarked $5billion for loans at preferential rates to private companies wishing to invest in countries with strong agricultural productivity potential, with purchases already taking place in Sudan, Egypt, Ethiopia and Kenya.[463] Due to overpumping of water for irrigation, such as occurred in Saudi Arabia, water tables are falling and millions of irrigation wells are going dry or are on the verge of doing so, particularly in the big three gain producing nations – the US, India and China[464], sparking fears for international food security and competition over land with access to water.

d) Topsoil depletion is occurring far faster than it is being replenished

Assessing the rate of soil erosion is of fundamental importance to understanding the impacts of land availability on food production. Soil erosion is known to be a key issue that could have significant impact over the next few years to decades and has differing impacts on different crops. The majority of soil degradation is caused by water, either from flooding or irrigation and wind. Poor farming practices, including ploughing, over-grazing and intensified planting, also contribute to depleting soil of vital nutrients which take thousands of years to build up – 6 inches of topsoil takes tens of thousands of years to create[465]. The majority of soil erosion figures are based on models such as the Universal Soil Loss Equation (USLE) which are increasingly being called into question as they very often under or overestimate actual observed soil erosion rates and there has not been a systematic process to validate

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[462] In Earth Policy Institute, 'Plan B 4.0 by the Numbers – The Global Food Supply', *Data Highlights* (10 February 2010) <http://www.earth-policy.org/data_highlights/2010/highlights7> [accessed March 2012] (Reproduced with permission.)

[463] John Vidal, 'How food and water are driving a 21st-century African land grab', *The Guardian* (7 March 2010) <http://www.guardian.co.uk/environment/2010/mar/07/food-water-africa-land-grab> [accessed March 2012]

[464] Lester R. Brown, 'Falling Water Tables and Shrinking Harvests', *World on the Edge* (Earth Policy Institute, 2011)

[465] Drake Bennett, 'Scientists focus on making better soil to help with food concerns', *The New York Times* (29 April 2008) [accessed March 2012]

their results[466]. The last world-wide study to observe actual soil degradation was in 1990[467]. However, the overall global trajectory remains valid even if local predictions are uncertain.

Around 40% of the world's agricultural land is seriously degraded.[468] Among the worst affected regions are Central America, where 75% of land is infertile, Africa, where a fifth of soil is degraded, and Asia, where 11% is unsuitable for farming.[469] Overall, the world is losing 10 million hectares of soil per year to soil erosion, and as a result, over the past 40 years, 30% of global arable land has become unproductive.[470] An article on InsideClimate News reports that the "Food and Agriculture Organization of the United Nations (FAO) warned for nearly a decade that 140 million hectares of high quality soil, mostly in Africa and Asia, would be degraded by 2010 unless better methods of land management were adopted"[471]. It goes on to report that in 2006, "researchers at Cornell University reported that soil around the world was being depleted at a rate that was 10 to 40 times faster than the rate it was being replenished", leading the authors of the study to conclude that so-called 'peak soil' was the second biggest environmental problem after population growth facing the planet.[472]

This trend is unequal across regions, with parts of the world more severely affected than others. For example, China is losing soil 57 times faster than nature can replace it, according to John Crawford, a professor at the University of Sydney's Institute of Soil Sciences.[473] In the United States, top soil is still being eroded 10 times faster than it can be replaced despite implementation of conservation practices, according to the National Academy of Sciences.[474] Desertification is one result, with China's desertification possibly the worst in the world. From 1950 to 1975 an average of 600 square miles (around 155,000 hectares) turned to desert each year and by the end of the 20th century, nearly 1,400 square miles (around 362,000 hectares) were going to desert annually.[475] Overall, 80% of the world's farming land has been found to be "moderately or severely eroded" according to a University of Sydney study presented at the 2010 Carbon Farming conference, suggesting that agricultural production has been able to keep pace with demand but only by taxing the soil fertility of the future.[476]

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[466] Evans, 2013, *Assessment and monitoring of accelerated water erosion of cultivated land – when will reality be acknowledged?,* Soil Use and Management, British Society of Soil Science
[467] Oldeman, Hakkeling & Sombroek, 1991, *World map of the status of human-induced soil degradation,* Global Assessment of Soil Degradation (GLASOD), International Soil Reference and Information Centre & United Nations Environment Programme.
[468] Ian Sample, 'Global food crisis looms as climate change and population growth strip fertile land', *The Guardian* (31 August 2007) [accessed March 2012]
[469] Ibid
[470] Susan S. Lang, "Slow, insidious' soil erosion threatens human health and welfare as well as the environment, Cornell study asserts', *Cornell University Chronicle Online* (20 March 2006) <http://www.news.cornell.edu/stories/March06/soil.erosion.threat.ssl.html> [accessed March 2012]
[471] Amy Westervelt, 'Peak Soil Has a Simple Fix, But Will We Manage It?', *InsideClimate News* (19 November 2009) <http://insideclimatenews.org/news/20091119/peak-soil-has-simple-fix-will-we-manage-it> [accessed March 2012]
[472] Ibid
[473] Ibid
[474] Ibid
[475] Lester Brown, 'Peak soil is no joke: Civilization's foundation is eroding', *Grist* (29 September 2010) <http://www.grist.org/article/civilizations-foundation-eroding> [accessed March 2012]
[476] Andrew Hough, 'Britain faces food crisis as world's soil 'vanishes in 60 years'', *The Telegraph*, (3 Feb 2010) [accessed March 2012]

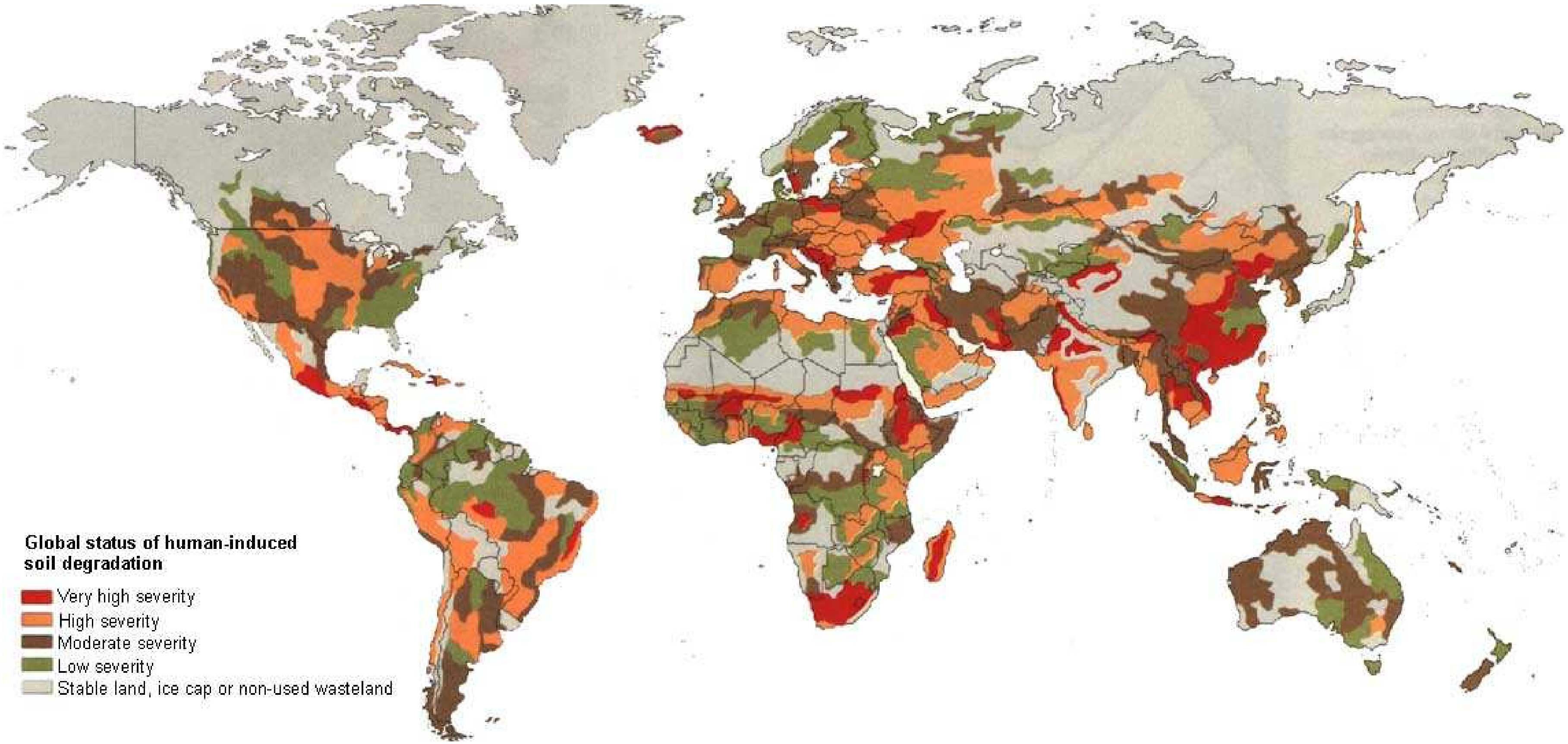

Figure 38: Global status of human induced soil degradation[477]

[477] In Agriculture and Consumer Protection Department – Food and Agricultural Organization of the United Nations (FAO), 'Dimensions of need: An atlas of food and agriculture', *FAO Corporate Document Repository* <http://www.fao.org/docrep/u8480e/U8480E0D.HTM> [accessed March 2012]

e) Private investment into land is increasing due to shortage

A report emerging from the World Agriculture Conference held in October 2011 on 'Capturing Investment Opportunities in Agriculture: An Expert View' urges investors that the time is ripe to reap financial rewards from agriculture.[478] It describes how concerns over food security, a growing world population and rising demand particularly from the developing world has put a spotlight on agriculture, drawing increased investor attention in the past few years. Loss of arable land worldwide is cited as a key driver for this expansion of capital injection into land assets. Land scarcity coupled with intensified competition and requirements for land use is creating basic supply/demand dynamics, causing land values to climb. Private investors are heeding these signals, with a growing array of institutions, from hedge funds to pension funds, buying up land internationally. Apparently driven by impending global food and land shortages, in the US there is a hedge fund that now owns enough farmland to make it the 15th largest farmer in the US.[479] In 2011, there was approximately $14 billion of private funds invested in agriculture and farmland with the number projected to grow tenfold over the next ten years.[480] Working through hedge funds, wealthy universities in the US have this year been found to be investing, up to $500 million, into African land deals with expected returns of up to 25%.[481] The NGO GRAIN found that some of the biggest players looking to profit from farmland are pension funds.[482] Pension funds currently hold US$23 trillion in assets, of which some US$100 billion are believed to be invested in commodities.[483] With reported 10 – 20% annual rates of return in this new asset class some US$5–15 billion are reportedly going into farmland acquisitions.[484] By 2015, these commodity and farmland investments are expected to double[485].

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[478] FC Business Intelligence, *World Agriculture Investment Overview: Expert Insights* (Oct 2011) <http://www.aginvestconference.com/documents/CapturingInvestmentOpportunitiesinAgriculture2011.pdf> [accessed March 2012]

[479] 'Hedge Fund Managers Pour Assets into Farmland', *GE Food Alert* <http://www.gefoodalert.org/hedge-fund-managers-pour-assets-into-farmland/> [accessed March 2012]

[480] Ibid

[481] John Vidal and Claire Provost, 'US universities in Africa 'land grab'', *The Guardian* (8 June 2011) <http://www.guardian.co.uk/world/2011/jun/08/us-universities-africa-land-grab> [accessed March 2012]

[482] 'Pension funds: key players in the global farmland grab', *Grain* (20 June 2011) <http://www.grain.org/article/entries/4287-pension-funds-key-players-in-the-global-farmland-grab> [accessed March 2012]

[483] Ibid

[484] Ibid

[485] Ibid

Table: Examples of pension funds investing in farmland (2010–2011)[486]

Fund	Total assets under management (AUM)	Global farmland investment portion…(% of AUM)	…and its status
AP2 (Second Swedish National Pension Fund)	SEK220 billion [US$34.6 billion]	US$500 million in grain farmlands in US, Australia and Brazil (1.4%)	Planned joint venture with TIAA–CREF. First forays into farmland investing were in 2010
APG (administering the National Civil Pension Fund), Netherlands	€220 billion [US$314 billion]	€1 billion (0.5%) [US$1.4 billion]	A planned increase
Ascension Health, USA	US$15 billion	Up to US$1.1 billion (7.5% target)	Looking to invest in farmland for the first time, to help meet a real assets target of 7.5% that is currently underachieved
CalPERS (California Public Employees' Retirement System), USA	US$231.4 billion	About US$50 million (0.2%): majority invested in agribusiness firms with huge int'l farmland holdings	Current
Dow Chemical, USA		not revealed	Farmland added recently. Aimed annual returns on US holdings: 8–12%
New Zealand Superannuation Fund	NZ$17.43 billion [US$14.2 billion]	NZ$500 million (3%) [US$407 million]	The 3% allocation has been made at the Fund's strategy level. First purchases into domestic farmland have started
PGGM (Pension Fund for Care and Well-Being), Netherlands	€90 billion [US$128 billion]	not revealed	May raise farmland allocation in 2011
PKA (Pensionskassernes Administration), Denmark	US$25 billion	US$370 million (1.5%)	In June 2011, made a first placement of US$50 million in Silver Street Capital's Silverland Fund.
Sonoma County Employees' Retirement System Association, USA			Expected to allocate 3% to UBS Agrivest Farmland Fund
TIAA–CREF (Teachers Insurance & Annuity Association – College Retirement Equities Fund), USA	US$426 billion	US$2 billion in 400 farms in North and South America, Australia and Eastern Europe (0.5%)	Current. They claim annual returns of 10%

[486] In ibid (Reproduced with permission.)

4.5.2 When will the constraint occur?

Soil	World Peak Estimate	Source	Date of Prediction
Before 2012	10 millennia ago	David Pimentel, Agricultural Ecologist, Cornell University[487]	?
By 2030	No topsoil left by 2070 (within 60 years)	John Crawford, University of Sydney[488]	2011
	No topsoil left between 40 – 80 years time	John Jeavons, Founder Ecology Action (non-profit)[489]	2010
After 2030	Run out of fertile topsoil or one or two more centuries	David Montgomery, Author 'Dirt: The Erosion of Civilizations'[490]	2008
No peak on horizon			

	World Peak Estimate	Date of Prediction
Palm Oil	Supply of land for palm oil to run out by 2020/2022 in Indonesia and Malaysia	Ken Arieff-Wong, Analyst, KL[491]
Phosphorus	Could peak by 2033	Soil Association[492]
	Enough to last several hundred years	International Fertilizer Development Centre[493]
	2030	Cordell, Drangert, White, Linköping University and University of Technology Sydney, *Global Environmental Change*[494]
	Readily available supplies may start running out at the end of this century	*Scientific American*[495]
	1989	Patrick Déry, The Oil Drum[496]

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[487] Ward Chesworth, 'Voices: Peak Soil: Does Civilization Have a Future?', *Earth Magazine* (15 April 2010) <http://www.earthmagazine.org/earth/article/32f-7da-4-f> [accessed March 2012]

[488] Andrew Hough, 'Britain facing food crisis as world's soil 'vanishes in 60 years", *The Telegraph* (3 February 2010)

[489] Larry Gallagher, 'The Joy of Dirt', *OdeWire* (1 Mar 2010), <http://odewire.com/50849/the-joy-of-dirt.html> [accessed March 2012]

[490] David R. Montgomery, *Dirt: The Erosion of Civilizations* (California: University of California Press, 2008)

[491] Kevin Brown, 'Asian palm oil: limited supply', *Financial Times: Beyondbrics* Blog (18 April 2011)

[492] Soil Association, 2010, *A rock and a hard place: peak phosphorous and the threat to food security*

[493] International Fertilizer Development Centre, *Press Releases - IFDC Report Indicates Adequate Phosphorus Resources Available to Meet Global Food Demands* (September 2010) <http://www.ifdc.org/Media_Info/Press_Releases/September_2010/IFDC_Report_Indicates_Adequate_Phosphorus_Resource> [accessed March 2012]

[494] Dana Cordell, Jan-Olof Drangert and Stuart White, 'The Story of Phosphorus', *Science Direct* (11 February 2009)

[495] David A. Vaccari, 'Phosphorus Famine: The Threat to Our Food Supply', *Scientific American Magazine* (3 June 2009) <http://www.scientificamerican.com/article.cfm?id=phosphorus-a-looming-crisis> [accessed March 2012]

Wheat	Genetic grain peaked in 1980s	R. Graybosch & C. J. Patterson, University of Nebraska, Lincoln, Oregon State University, *Crop Science*[497]
	Saudi Arabia reached peak grain in 1994	Lester Brown, Earth Policy Institute[498]
	World per capita grain production peaked in the mid-1980s	Niall Ferguson[499]

4.6 Water

4.6.1 What is the evidence for a resource constraint?

a) Regional water scarcity is increasing (demand exceeding supply)

In some regions, water use exceeds the amount of water that is naturally replenished every year. Water is an incredibly regionally-specific resource as it is very expensive and inefficient to move around. Thus regional constraints, and peaks, are more relevant when looking at water resource limits. About one-third of the world's population lives in countries with moderate-to-high water stress, defined by the United Nations to be water consumption that exceeds 10% of renewable freshwater resources.[500] According to a report by the corporate-formed Water Resources Group, led by the consultancy McKinsey & Company, by 2030, if there are no efficiency gains, the global water demand will be 40% greater than today's "accessible, reliable, environmentally sustainable supply", while about one-third of the population, concentrated in developing countries, will live in basins where this water deficit is larger than 50%.[501]

Water scarcity is caused by a variety of factors, not only physical scarcity. Other factors include poor conservation measures, water pollution, poor distribution and infrastructure channels and bad water management. One quarter of the global population live in developing countries in which water shortages are caused by a lack of infrastructure to withdraw water from rivers and aquifers.[502] Facing a growing population, combined with the

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[496] Patrick Déry and Bart Anderson, 'Peak Phosphorus', *The Oil Drum* (17 July 2007) <http://www.theoildrum.com/node/2882> [accessed March 2012]

[497] Michael Price, 'Has Wheat Peaked?', *Science Now* (25 August 2010) <http://news.sciencemag.org/sciencenow/2010/08/has-wheat-peaked.html?etoc> [accessed March 2012]

[498] Marianne Lavelle, 'Forget Saudi Peak Oil—Worry About Peak Grain', *US News* (21 May 2008) <http://money.usnews.com/money/blogs/beyond-the-barrel/2008/05/21/forget-saudi-peak-oil--worry-about-peak-grain> [accessed March 2012]

[499] Niall Ferguson, 'Worry about bread, not oil', *The Telegraph* (29 July 2007) <http://www.telegraph.co.uk/comment/personal-view/3641586/Worry-about-bread-not-oil.html> [accessed March 2012]

[500] Dr. Peter H. Gleick and Meena Palaniappa, 'The Concept of Peak Water', *On The Water Front* (2010) <http://www.siwi.org/documents/Resources/Best/2010/2011_OTWF_Peter_Gleick.pdf> [accessed March 2012] pp. 41-49

[501] Stephen Leahy, 'Peak water has already come and gone', *The Guardian* (23 March 2011) <http://www.guardian.co.uk/environment/2011/mar/23/peak-water> [accessed March 2012]

[502] World Health Organization, *Fact File: Water Scarcity* <http://www.who.int/features/factfiles/water/water_facts/en/index7.html> [accessed March 2012]

poor transportability of water, the risks are that more people will be forced to rely on unsafe sources, for example for drinking, bathing and washing or for use in agriculture. More than 10% of people worldwide currently consume food that has been irrigated by wastewater that can contain chemicals unsuitable for human consumption and disease-causing organisms.[503] Thus water limits are being demonstrated not only geo-physically but also economically and socially. Climate change is likely to exacerbate these factors.

b) Major rivers are running dry and water tables are falling

Peter Gleick defines three types of 'peak water': peak renewable, peak non-renewable and peak ecological water resources.[504] 'Peak renewable' refers to the use of 'renewable' stocks of water, such as within the flows of rainfall, rivers, streams and groundwater basins. These are theoretically unlimited, as they are renewed over relatively short timeframes. However, when human demand from a watershed reaches 100% of the renewable supply, no more can be taken and a limit *is* reached. Gleick finds that for a number of major river basins, we have reached the point of peak renewable water limits, including the Colorado River in the United States.[505] All of the water of the Colorado (in fact more than 100% of the average flow) is already spoken for through legal agreements with the seven US states and Mexico and in an average year river flows now often fall to zero before they reach their ends.[506] In November 2011, the US Bureau of Reclamation published a 'Colorado River Basin Water Supply and Demand Study' in which it examined historic and projected supply and demand trends of the Colorado river basin to assess current and future imbalances, concluding that the river is over-allocated and that this is only likely to be exacerbated in the future.

This is also true for a growing number of rivers around the world, including the Ganges, Nile, Jordan and Yangtze.[507] The Earth Policy Institute find that some rivers have disappeared entirely, while some of the major rivers are reduced to a trickle or run completely dry before reaching their end. The following table highlights some key river basins with severe impacts:

[503] Ibid
[504] Peter Gleick, 'Is the U.S. Reaching Peak Water?', *Forbes* (7 September 2011) <http://www.forbes.com/sites/petergleick/2011/09/07/is-the-u-s-reaching-peak-water/> [accessed March 2012]
[505] Ibid
[506] Ibid
[507] Matthew Power, 'Peak Water: Aquifers and Rivers Are Running Dry. How Three Regions Are Coping', *Wired* (21 April 2008) <http://www.wired.com/science/planetearth/magazine/16-05/ff_peakwater?currentPage=all> [accessed March 2012]

Table: Major Rivers Running Dry[508]

Major Rivers Running Dry	
River	**Condition**
Amu Darya	The Amu Darya, which originates in the mountains of Afghanistan, is one of the two rivers that feed into the Aral Sea. Soaring demands on this river, largely to support irrigated agriculture in Uzbekistan, sometimes drain it dry before it reaches the sea. This, along with a reduced flow of the Syr Darya—the other river feeding into the sea—helps explain why the Aral Sea has shrunk by more than half over the last 40 years.
Colorado	All the water in the Colorado, the major river in the southwestern United States, is allocated. As a result, this river, fed by the rainfall and snowmelt from the mountains of Colorado, now rarely makes it to the Gulf of California.
Fen	This river, which flowed from the northern part of China's Shaanxi province and empties into the Yellow River at the province's southern end, has literally disappeared as water withdrawals upstream in the watershed have dropped the water table, drying up springs that once fed the river.
Ganges	Some 300 million people of India live in the Ganges basin. Flowing through Bangladesh en route to the Bay of Bengal, the Ganges has little water left when it reaches the bay.
Indus	The Indus, originating in the Himalayas and flowing west to the Indian Ocean, feeds Pakistan's irrigated agriculture. It now barely reaches the ocean during much of the year. Pakistan, with a population of 157 million projected to reach 349 million by 2050, is facing trouble.
Nile	In Egypt, a country where it rarely ever rains, the Nile is vitally important. Already reduced to a trickle when it reaches the Mediterranean, it may go dry further upstream in the decades ahead if, as projected, the populations of Sudan and Ethiopia double by 2050.
Yellow	The cradle of Chinese civilization, the Yellow River frequently runs dry before it reaches the sea.

The second type of peak water described by Gleick is "peak non-renewable", which refers to stocks of water with very slow recharge rates, such as groundwater aquifers. When the use of water far exceeds natural recharge rates, this stock of groundwater will be depleted or fall to a level where the cost of extraction exceeds the value of the water when used, similar to the bell-shaped production curve of oilfields. Continued production of such water beyond natural recharge rates will become increasingly difficult and expensive as groundwater levels fall, leading to a peak of production, followed by diminishing withdrawals and use. According to Gleick, this is already happening in the Ogallala Aquifer in the Great Plains of the United States, the North China plains, parts of California's Central Valley, and numerous regions in India.[509] In these basins, extraction does not necessarily fall to zero, but current rates of

[508] In Lester R. Brown, Chapter 6: 'Stabilising Water Tables: Rivers Running Dry', *Outgrowing the Earth: The Food Security Challenge in an Age of Falling Water Tables and Rising Temperatures'*, (Washington D.C.: Earth Policy Institute, 2004) <http://www.earth-policy.org/books/out/ote6_3> [accessed March 2012] (Reproduced with permission.)
[509] Peter Gleick, 'Is the U.S. Reaching Peak Water?', *Forbes* (7 September 2011)

pumping are unsustainable, and with a significant fraction of current global agricultural production depending on non-renewable groundwater, only set to increase, the risks are high.

In 2009 the World Economic Forum published a report ahead of the World Water Forum warning that the world is on the verge of “water bankruptcy” threatening, among other things, the stability of agricultural productivity.[510] It foresaw that by 2030, water scarcity could cut harvests by 30% - equivalent to all the grain grown in the US and India – within the context of rising demand and population growth.[511] The Earth Policy Institute similarly finds that the world is incurring a vast “water deficit”, with half the world’s population living in countries where water tables are falling as aquifers are being depleted, largely down to agriculture which uses 70% of water used globally.[512]

c) Ecological pressures due to human appropriation of water are increasing

A third type of ‘peak water’ described by Gleick is “peak ecological” which refers to the point where taking more water for human use leads to ecological disruptions greater than the value that this increased water provides to humans.

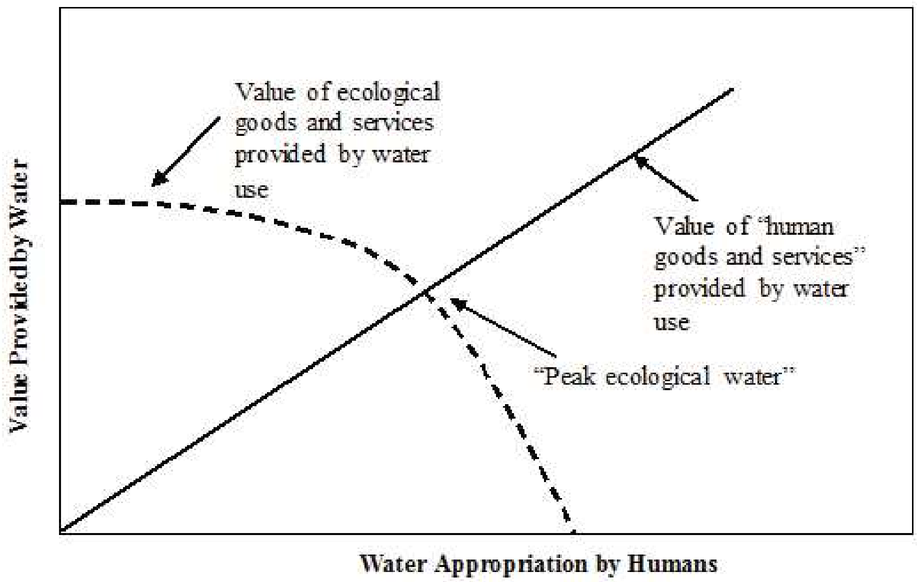

Figure 39: Peak Ecological Water[513]

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[510] Geoffrey Lean, 'Water scarcity 'now bigger threat than financial crisis'', *The Independent* (15 March 2009) <http://www.independent.co.uk/environment/climate-change/water-scarcity-now-bigger-threat-than-financial-crisis-1645358.html> [accessed March 2012]

[511] Ibid

[512] Lester R. Brown, Chapter 2 ‘Falling Water Tables and Shrinking Harvests’, *World on the Edge: How to Prevent Environmental and Economic Collapse* (Washington D.C.: Earth Policy Institute, 2011) <http://www.earth-policy.org/images/uploads/book_files/wotech02.pdf> [accessed March 2012]

[513] In Dr. Peter H. Gleick and Meena Palaniappa, ‘The Concept of Peak Water’, *On The Water Front* (2010) p. 46

Some estimates state that humans already appropriate almost 50% of all renewable and accessible freshwater flows, leading to significant ecological disruptions.[514] Since 1900, half of the world's wetlands have disappeared.[515] The number of freshwater species has decreased by 50% since 1970, faster than the decline of species on land or in the sea.[516] Although quantifying the value and measurements of 'peak ecological' water is difficult, the concept draws attention to the way in which ecosystem services have been highly discounted and under-valued in the past and the pressures human water use are placing on biodiversity.

A 2010 study published in the journal *Nature* which mapped global threats to human water security and river biodiversity found that 80% of the world's human population is exposed to high levels of threats to water scarcity while at the same time habitats associated with 65% of continental water discharge are moderately to highly threatened.[517] The chart below depicts the current status of global threats to river biodiversity as mapped out by the researchers:

[514] Ibid, p. 42
[515] Ibid, p.47
[516] Ibid
[517] C. J. Vörösmarty et al., 'Global threats to human water security and river biodiversity', *Nature,* Vol. 467, No. 7315 (30 September 2010) <http://www.nature.com/nature/journal/v467/n7315/full/nature09440.html> [accessed March 2012]

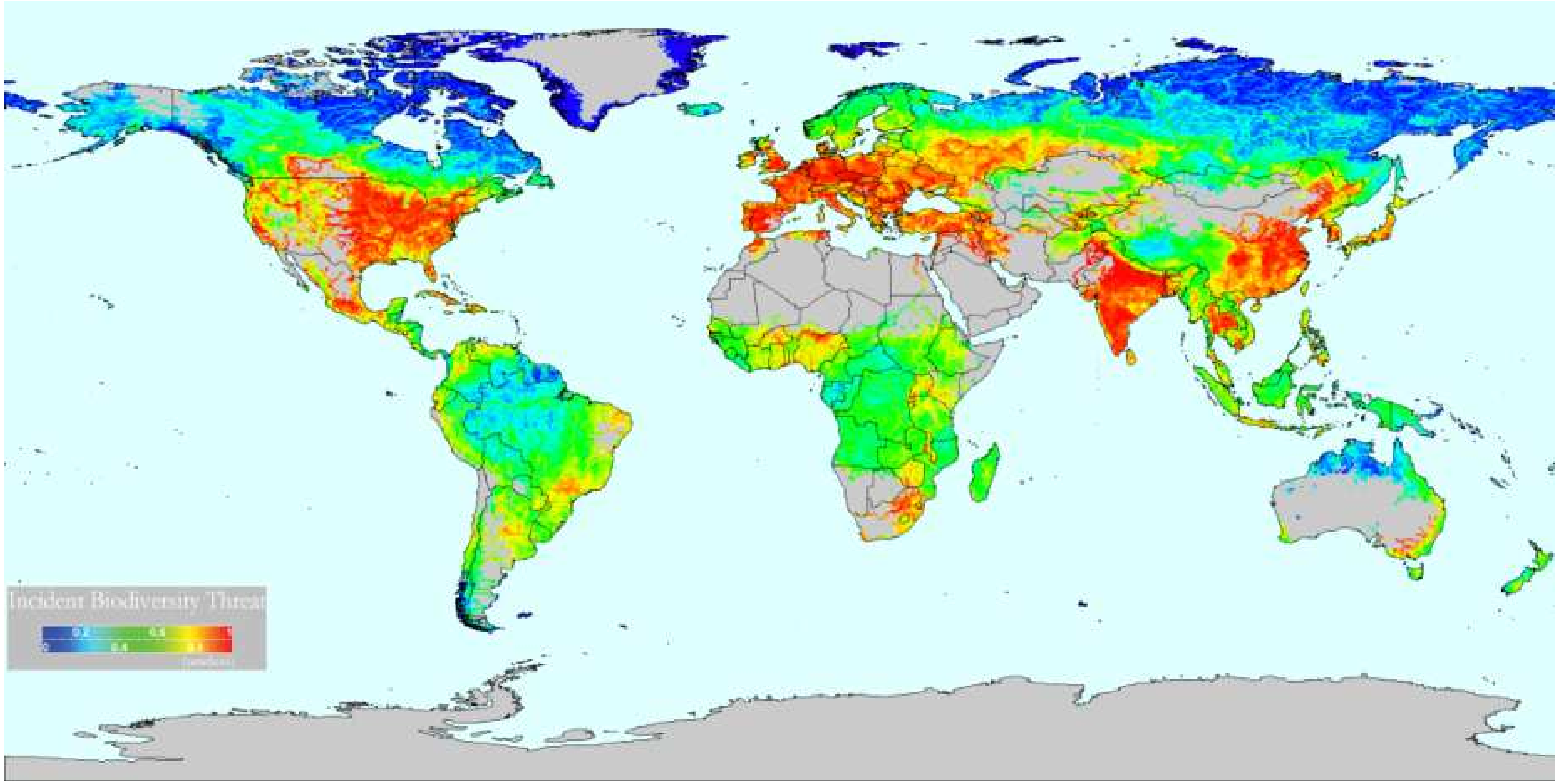

Figure 40: Global geography of incident threat to human water security and biodiversity[518]

[518] In 'Global Threats to Human Water Security and River Biodiversity', *Rivers in Crisis: River Threat.net* <http://riverthreat.net/> [accessed March 2012]

d) Glaciers are in accelerating retreat worldwide

Retreating glaciers around the world, due to climate change, are causing growing concern over water shortages. A 2011 study of the Cordirella Blanca mountain range in Peru is the first of its kind to document the threshold that marks the transition from an increased flow of water, when the glacier first starts to retreat, to an ever-diminishing discharge, eventually leading to severe water shortages.[519] The glacier has been in retreat for decades, but recently has started to disappear at a faster rate and for the first time the flow of run-off from the glacier has shrunk, leading the scientists behind the study to state that the point of "peak discharge" has been passed, with less water reaching the Rio Santa valley, where millions of people rely on the supply for irrigation, drinking water and industrial use, during the June to November dry season.[520] Other glaciers in retreat around the world include those in the Himalayas, where hundreds of meltwater lakes have appeared, in Greenland, where the melting of the ice sheet and related glaciers in 2011 was the third most extensive since 1979 when records began, and in the European Alps, where glaciers in the French Alps have lost 25% of their area over the last 40 years.[521] The following graph from the International Panel on Climate Change reports the global trend for retreating glaciers from 1700 – 2000:

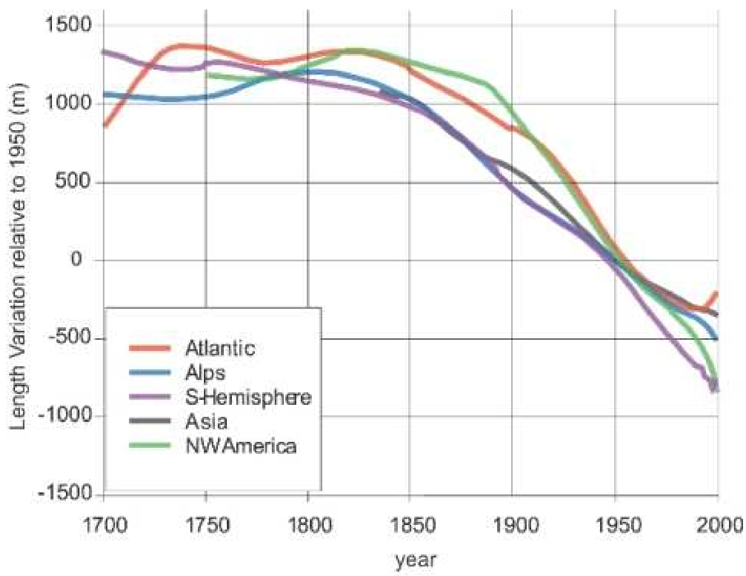

Figure 41: Large-scale regional mean length variations of glacier tongues.
NB: The raw data are all constrained to pass through zero in 1950. The curves shown are smoothed with the Stineman method and approximate this. Glaciers are grouped into the following regional classes: SH (tropics, New Zealand, Patagonia), northwest North America (mainly Canadian Rockies), Atlantic (South Greenland, Iceland, Jan Mayen, Svalbard, Scandinavia), European Alps and Asia (Caucasus and central Asia).[522]

519 Jeffrey T. Bury et al. 'Glacier recession and human vulnerability in the Yanamarey watershed of the Cordillera Blanca, Peru', *Climatic Change* Vol. 105 No. 1 – 2, (2011) <http://www.springerlink.com/content/h13461005uj5q427/> [accessed March 2012] pp. 179 – 206

520 Stephanie Pappas, 'Shrinking Glaciers Point to Looming Water Shortage', *Live Science* (8 December 2011) <http://www.livescience.com/17379-shrinking-glaciers-water-shortages.html> [accessed March 2012]

521 Steve Connor, 'Glaciers in retreat around the world', *The Independent* (8 December 2011) <http://www.independent.co.uk/environment/climate-change/glaciers-in-retreat-around-the-world-6274223.html> [accessed March 2012]

522 Fig 4.13 in Peter Lemke and Jiawen Ren et al., 'Observations: Changes in Snow, Ice and Frozen Ground', *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the*

e) Increasing use of technological fixes to draw out fresh water

A report published in 2001 examined the impact of water scarcity on the growth of the desalinisation market over the next 25 years and concluded that "desalination, along with wastewater reuse and water importation can provide a means of increasing the supply of available fresh water in the regions of the world where water is scarce".[523] This is largely to do with the rising cost of water supplies which has made these technologies cost-competitive. Water scarcity is found to be the driving force behind the increased development of desalinisation plants. According to the International Desalination Association (IDA), there has been accelerated growth in the desalination market in recent years.[524] Between 2007 – 2009 installed capacity of seawater desalination grew by 29.6%.[525] The Middle East is the largest market for this technology, but with large-scale programme also underway in Australia, Algeria and Spain – significantly water-stressed regions.

The outlook report noted that the recession had caused a slowdown in new capacity, but that since 2010 this has begun to rise again, with notable plants in the UAE, Morocco and Saudi Arabia. The market value of desalination equipment in 2010 was $2.9billion, rising at a compound annual growth rate of 13.8%; by 2015, the market is expected to be worth $5.5billion.[526] The growing reliance on and attractiveness of such technology indicates rising pressures to source water for human needs. One extreme case in point is the recent example of the nation-state of Tuvalu, which in October 2011 faced such severe water shortages due to rising sea levels which contaminated their groundwater supplies, that they were forced to rely on rehydration packets and desalination equipment provided by Australia and New Zealand.[527].

Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. by Solomon, S., D. et al. (Cambridge: Cambridge University Press, 2007) <http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter4.pdf> [accessed March 2012] (Reproduced with permission.)

[523] Ingrida Bremere et al., 'How water scarcity will ffect the growth in the desalination market in the coming 25 years', *Desalination,* Vol. 138 (2001) <http://www.desline.com/articoli/4127.pdf> [accessed March 2012] pp. 7–15

[524] Lisa Henthorne, 'The Current State of Desalination', International Desalination Association/Global Water Intelligence (20 Nov 2009) <http://www.idadesal.org/PDF/the%20current%20state%20of%20desalination%20remarks%20nov%2009%20by%20lisa%20henthorne.pdf> [accessed March 2012]

[525] Ibid

[526] Lis Stedman, 'GLOBAL: Strong growth for desalination market', *IWA Publishing* (29 March 2011) <http://www.iwapublishing.com/template.cfm?name=news698> [accessed March 2012]

[527] Bryan Walsh, 'Why the World May Be Running Out of Clean Water', *Time* (18 October 2011) <http://www.time.com/time/health/article/0,8599,2097159,00.html> [accessed March 2012]

4.6.2 When will the constraint occur?

	World Peak Estimate	Source	Date of Prediction
Before 2012	Saudi Arabia hit peak water 10 years ago	The Oil Drum[528]	2008
	Cyprus has hit peak water; Yemen to run out by 2015; Pakistan under pressure	Alexander Bell, author of 'Peak Water', in *The New Statesman*[529]	2010
	Peak water "come and gone"	*Guardian* news[530]	2011
	In many parts of the world already hit peak water, including USA – which hit peak water in the 1970s	Peter Gleick, Pacific Institute, California[531] [532]	2011
	Peruvian watershed likely passed peak water due to melting glaciers	Michel Baraër, McGill University, Montreal[533]	2011
By 2020	"Dawning era of peak water"	Matthew Power, *Wired* magazine[534]	2008
By 2030	By 2030 the global water demand will be 40% greater than today's "accessible, reliable, environmentally sustainable supply"	McKinsey & Company[535]	2009
After 2030	N/A		
No peak on horizon	N/A		

[528] Ugo Bardi, 'Peak Water in Saudi Arabia', *The Oil Drum* (29 January 2008) <http://www.theoildrum.com/node/3520> [accessed March 2012]
[529] Alexander Bell, 'World at War Over Water', *New Statesman* (28 March 2010) <http://www.newstatesman.com/environment/2010/03/water-cyprus-pakistan-yemen> [accessed March 2012]
[530] Stephen Leahy, 'Peak water has already come and gone', *The Guardian* (23 March 2011)
[531] Beth Lebwohl, Deborah Byrd and Eleanor Imster, 'Peter Gleick on Peak Water', *EarthSky* (20 June 2011) <http://earthsky.org/water/peter-gleick-on-peak-water> [accessed March 2012]
[532] Peter Gleick, 'Is the U.S. Reaching Peak Water?', *Forbes* (7 September 2011)
[533] Stephanie Pappas, 'Shrinking Glaciers Point to Looming Water Shortage', *Live Science* (8 December 2011)
[534] Matthew Power, 'Peak Water', *Wired* (21 April 2008)
[535] 2030 Water Resources Group, *Charting Our Water Future* (2009)

4.7 Commodities

4.7.1 What is the evidence for a resource constraint?

a) Growing concern over supply gaps as demand surges forward

Over the course of the 20th Century, global resource use has increased eight-fold.[536] The UNEP graph below (based on data from Krausmann et. al 2009[537]) charts this expansion over the period 1900 – 2005 across four major material classes: biomass, fossil energy carriers, ores and industrial materials and construction materials:

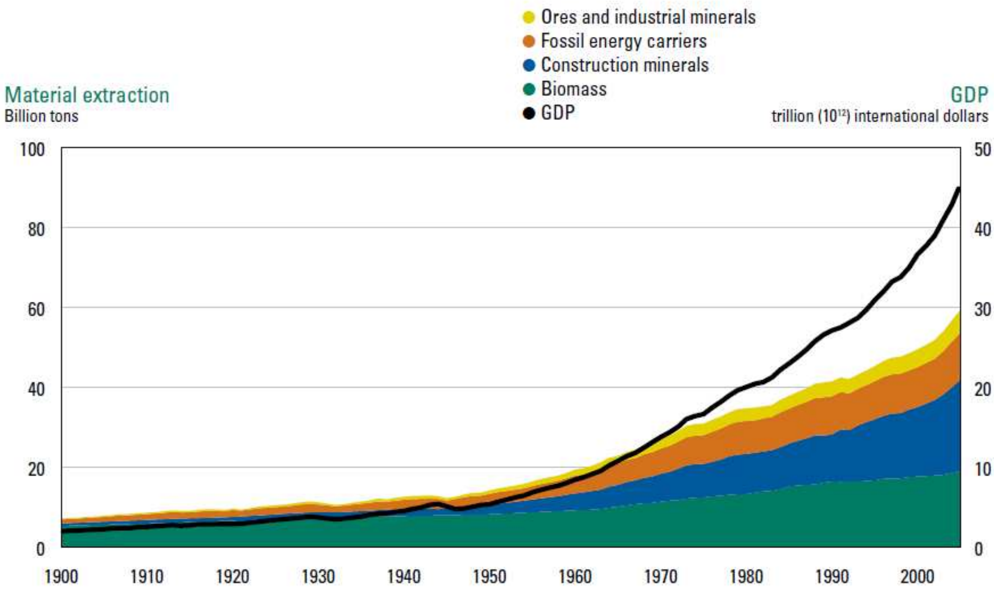

Figure 42: Global material extraction in billion tons, 1900 - 2005[538]

In recent years, strong industrial production growth in developing countries is leading to a further rapid increase in demand for base metals, such as aluminium, copper, nickel, zinc, lead and iron ore, because they are prime inputs into manufactured goods and large scale infrastructure projects.[539] The speed of current growth is outpacing past trends. Over the period 1970 – 2004, aluminium consumption increased by more than three times, copper and zinc consumption increased about twofold and lead consumption increased about one

[536] UNEP, *Decoupling natural resource use and environmental impacts from economic growth*, A Report of the Working Group on Decoupling to the International Resource Panel, M. Fischer-Kowalski, M. Swilling, E. U. von Weizsäcker, Y. Ren, Y. Moriguchi, W. Crane, F. Krausmann, N. Eisenmenger, S. Giljum, P. Hennicke, P. Romero Lankao, A. Siriban Manalang, S. Sewerin, (Switzerland: UNEP, 2011) <http://www.unep.org/resourcepanel/decoupling/files/pdf/decoupling_report_english.pdf> [accessed March 2012]

[537] F. Krausmann et al., 'Growth in global materials use, GDP and population during the 20th century', *Ecological Economics*, Vol. 68 (10) (2009) pp. 2696-2705.

[538] In UNEP, *Decoupling natural resource use and environmental impacts from economic growth*, (Switzerland: UNEP, 2011), p. xiv

[539] Access Economics Pty Ltd for Minerals Council of Australia, 'Global Commodity Demand Scenarios', (23 May 2008) <http://www.minerals.org.au/file_upload/files/resources/vision2020/V2020_Phase_1_ACCESS_GLOBAL.pdf> [accessed March 2012]

and a half times.[540] Over the next 15 – 20 years, a much shorter time period, Rio Tinto have projected a further doubling of demand for iron ore, copper and aluminium.[541]

There is growing concern, however, that demand is increasingly bumping up against supply constraints. In 2011, demand for copper will exceed supply by 435,000 – 635,000 tonnes, the largest gap since 2004.[542] BHP Billiton expects this gap to climb to 10 million tonnes by 2020.[543] Demand for zinc, the fourth most used metal in the world after iron, aluminium and copper, is also set to ramp up by 2 – 3% a year[544], however, every year the level of supply from zinc mines is falling[545] and is expected to peak, according to Credit Suisse, in 2012, due to zinc mine closures and depletions.

Credit Suisse forecasts that, although current supply-demand is relatively in balance, by 2016 global demand for zinc will be 16.6kts, but the world's mines will be able to produce only 10.2kts.[546] For iron ore, while world production has doubled over the past decade, prices have risen 13-fold, mainly as a result of supply limitations.[547] In August 2011, BHP Billiton's CEO, Marius Kloppers, was reported to state that iron ores supplies were being "over-estimated" and that supplies were already at their limit, amidst reports that prices had hit record highs of $180/tonne.[548] The head of exploration and mining at Rio Tinto, on the other hand, has said that there is no way the world is nearing a peak in iron ore, since production is still expanding, however, he admitted that the world will likely increasingly need to turn to lower grades to match demand.[549]

Alongside demand for base metals, demand for precious metals and so-called 'rare earth elements', used primarily as key inputs in high-tech applications, including within the defense, automobile, IT, mobile technology and clean-energy industries, is also surging.

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540 Rogich, D.G., and Matos, G.R., 'The global flows of metals and minerals', *U.S. Geological Survey Open-File Report 1355* (2008) <http://pubs.usgs.gov/of/2008/1355/pdf/ofr2008-1355.pdf> [accessed March 2012] pp. 1-11

541 Vivek Tulpulé, 'Outlook For Metals And Minerals', *Rio Tinto* (10 February 2011) <http://www.riotinto.com/documents/Investors/Outlook2010FullYearResults.pdf> [accessed February 2011]

542 Jae Hur and Ichiro Suzuki, 'Global copper demand to outpace supply', *China Daily* (21 January 2011) <http://www.chinadaily.com.cn/bizchina/2011-01/21/content_11896291.htm> [accessed March 2012]

543 Martin Creamer, 'World short of copper, 10Mt supply gap in 2020 – BHP', *Mining Weekly* (2 October 2009) <http://www.miningweekly.com/article/world-short-of-copper-10mt-supply-gap-in-2020-bhp-2009-10-02> [accessed March 2012]

544 'Zinc', *Inmet Mining* (2006) <http://www.inmetmining.com/ourmarkets/zinc/default.aspx> [accessed March 2012]

545 Tom Bulford, 'Zinc: the forgotten metal set to shine', *Money Week* (14 April 2010) <http://www.moneyweek.com/investments/commodities/commodities-metals-zinc-price-01506> [accessed March 2012]

546 Tom Bulford, 'Zinc: the forgotten metal set to shine', *Money Week* (14 April 2010)

547 'Crowded out: Chinese demand had ended a century of steadily falling raw-material costs for rich-world consumers', *The Economist* (24 September 2011) <http://www.economist.com/node/21528986> [accessed March 2012]

548 Frik Els, 'Iron ore price scales $180/tonne to within reach of record highs', *Mining.com* (25 August 2011) <http://www.mining.com/2011/08/25/iron-ore-price-scales-180tonne-to-within-reach-of-record-highs/> [accessed March 2012]

549 Angus Mcdowall, 'CORRECT (10/5):Peak Iron Ore Not On The Horizon - Rio Tinto Executive', *ADVFN* <http://www.advfn.com/nyse/StockNews.asp?stocknews=RTP&article=44678973> [accessed March 2012]

Investment demand in gold and silver has risen steeply against the backdrop of the recent economic crisis.[550] According to a Congressional Research Service report to US Congress, world demand for rare earth elements was estimated at 136,100 tons in 2010 and is projected to reach between 185,000 - 210,000 tonnes per year by 2015.[551] China's demand alone is anticipated to reach between 73,000 to 130,000 metric tonnes by 2015. The report concludes that although new mine production may be able to make up the difference, indeed create excess supply, for some lighter elements (such as cerium, lanthanum, and praseodymium), several forecasts show that there will likely be shortfalls of other light rare earth (LREEs) and several heavier rare earth elements (HREEs), such as, dysprosium, terbium, neodymium, europium and erbium.

China produces 97% of the world's rare earth metals, but over the past 6 years has steadily reduced its export quotas[552] , by as much as 72% by 2011[553], leading some, such as the European Union, to also fear that shortages are imminent[554], particularly as the growth of emerging technologies for high-tech, low-carbon production is pushing up competition for these strategic metals even further.[555] Others, however, are noting that this will lead to increased production elsewhere to make up for the shortfall.[556] However, if this need is not met, there will be a significant supply gap as the graph below illustrates:

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550 'The rapid growth of global silver investment demand', *Commodity Online* (11 November 2011) <http://www.commodityonline.com/news/the-rapid-growth-of-global-silver-investment-demand-43648-3-1.html> [accessed March 2012] and Mark O'Byrne , 'Surging Metal Demand a 'Global Phenomenon'', *Resource Investor* (17 February 2011) <http://www.resourceinvestor.com/News/2011/2/Pages/Surging-Metals-Demand-a-Global-Phenomenon-Voracious.aspx> [accessed March 2012]

551 Marc Humphries, 'Rare Earth Elements: The Global Supply Chain', *Congressional Research Service: Report for Congress* (6 September 2011) <www.fas.org/sgp/crs/natsec/R41347.pdf> [accessed March 2012]

552 Lee Levkowitz and Nathan Beauchamp-Mustafaga, U.S.-China Economic and Security Review Commission Staff Backgrounder, *China's Rare Earths Industry and its Role in the International Market*, U.S.-China Economic and Security Review Commission (3 Nov 2010) <http://www.uscc.gov/researchpapers/2011/RareEarthsBackgrounderFINAL.pdf> [accessed March 2012]

553 Ian Cooper, 'Bet on This Rare Earth Stock Next', *Wealth Daily* (2 June 2011) <http://www.wealthdaily.com/articles/elissa-resources-eliv-stock/3107> [accessed March 2012]

554 James Kanter, 'Europe Sounds Alarm on Minerals Shortage', *The New York Times* (16 June 2010) <http://green.blogs.nytimes.com/2010/06/16/europe-sounds-alarm-on-minerals-shortage/> [accessed March 2012]

555 Strategically Important Metals - Science and Technology Committee, 'Trade and geopolitics', *Parliamentary Business: Publications and Records* (17 May 2011) <http://www.publications.parliament.uk/pa/cm201012/cmselect/cmsctech/726/72606.htm> [accessed March 2012]

556 'Minor & Light Metals / Rare Earths & Yttrium: Market Outlook to 2015', *Roskill* (11 November 2011) <http://www.roskill.com/reports/minor-and-light-metals/rare-earths> [accessed March 2012]

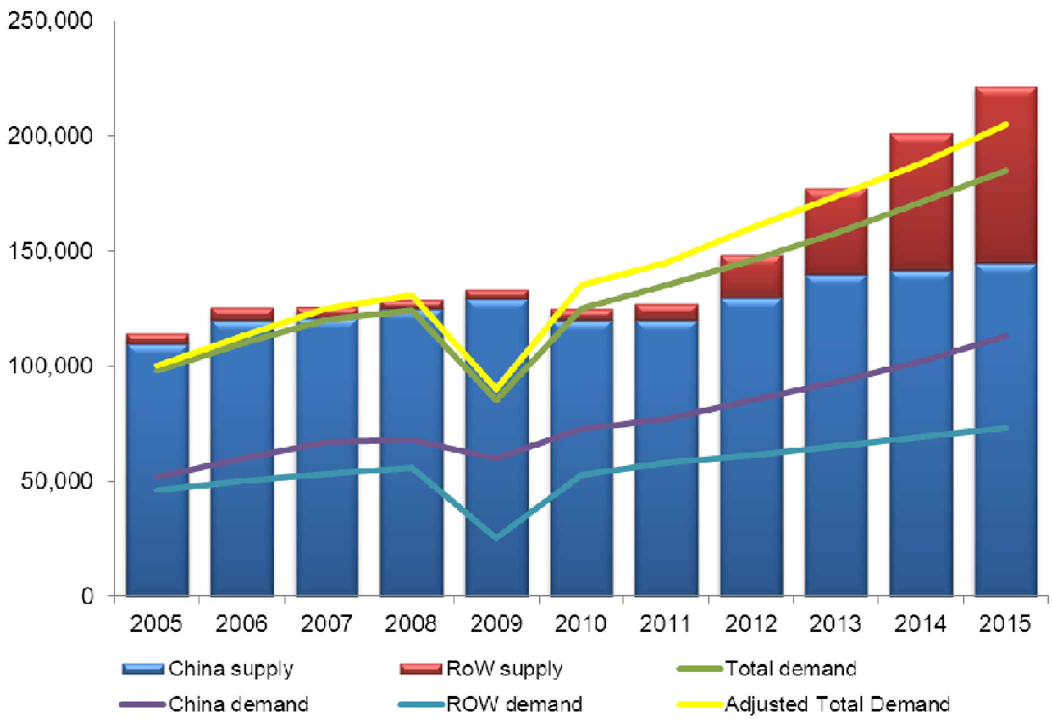

Figure 43: Global supply demand balance 2010 – 2015 (tREO)[557]

PricewaterhouseCoopers in a December 2011 survey of senior industry executives on 'Minerals and Metals Scarcity in Manufacturing', found that risk arising from minerals and metals scarcity is expected to increase across all industries in the next five years.[558] Their survey showed that renewable energy (78%), automotive (64%) and energy & utilities (57%) are currently experiencing instability of supply and that the aviation, high tech and infrastructure industries in particular believe they will see a high rise of instability of supply from now to 2016 primarily due to rising demand and geopolitical constraints followed by extraction shortages.[559]

In a study of 57 Non-renewable Natural Resources (NNRs) based on US Geological Survey and US Energy Information Administration data published on the Institute for the Study of Energy and Our Future's online journal website 'The Oil Drum' in 2010, Chris Clugston found that, overall, 50 NNRs (88%) experienced some level of global scarcity during the pre-recession years of the 21st Century (2000 – 2008), as summarised in the table below:

[557] In Judith Chegwidden and Dudley J Kingsnorth, 'Rare earths – an evaluation of future and current supply', Roskill Information Services Ltd., Industrial Minerals Company of Australia Pty., Paper presented at the TREM meeting (2011), Available at <http://www.slideshare.net/RareEarthsRareMetals/rare-earths-an-evaluation-of-current-and-future-supply> [accessed March 2012] (Reproduced with permission.)

[558] PriceWaterhouseCoopers, 'Minerals and metals scarcity in manufacturing: the ticking time bomb: Sustainable Materials Management', *PWC* (December 2011) <http://www.pwc.com/en_GX/gx/sustainability/research-insights/assets/impact-of-minerals-metals-scarcity-on-business.pdf> [accessed March 2012]

[559] Ibid

Table: Pre-recession (2000 – 2008) Global NNR Scarcity Summary:[560]

Extremely Scarce (6)	Very Scarce (21)	Moderately Scarce (22)	Marginally Scarce (1)	Not Scarce (7)
Bromine	Aluminum	Antimony	PGM	Arsenic
Gold	Bauxite	Beryllium		Barite
Mercury	Cadmium	Bismuth		Boron
Tantalum	Cement	Coal		Diamond
Tellurium	Chromium	Cobalt		Garnet
Thallium	Copper	Gallium		Lithium
	Fluorspar	Germanium		Niobium
	Magnesium Compounds	Graphite		
	Molybdenum	Gypsum		
	Natural Gas	Indium		
	Nickel	Iron Ore		
	Nitrogen (Ammonia)	Lead		
	Oil	Lime		
	Phosphate Rock	Manganese		
	Potash	Salt		
	REM	Silicon		
	Rhenium	Silver		
	Selenium	Soda Ash		
	Strontium	Tin		
	Sulfur	Vanadium		
	Tungsten	Zinc		
		Zirconium		

A further 23 of 26 NNRs analysed for potential permanent global supply shortfall were found to be likely to fall in this category by the year 2030:

Table: Permanent Global NNR Supply Shortfall (by 2030) Probability Summary[561]**:**

Permanent Global NNR Supply Shortfall (by 2030) Probability Summary

Nearly Certain Probability (5)	Very High Probability (8)	High Probability (10)	Low Probability (3)
Cadmium	Cobalt	Chromium	Bauxite
Gold	Lead	Coal	REM
Mercury	Molybdenum	Copper	Tin
Tellurium	PGM	Indium	
Tungsten	Phosphate Rock	Iron Ore	
	Silver	Lithium	
	Titanium	Magnesium Compounds	
	Zinc	Natural Gas	
		Nickel	
		Oil	
		Phosphate Rock	

Furthermore, over this time period, annual global production level growth rates associated with 34 of the 57 analysed NNRs (59%) decreased in comparison to 20th century growth rates, or became negative, while annual global price level growth rates associated with 51 of the 57 analysed NNRs (89%) increased in comparison to 20th century growth rates.[562] The study concludes that "Generally slowing or declining global NNR production growth in conjunction with generally increasing global NNR prices indicate increasing NNR scarcity during the early years of the 21st century—annual global NNR supplies were increasingly unable to keep pace with ever-increasing global demand."[563]

[560] In Chris Clugston, 'Increasing Global Nonrenewable Natural Resource Scarcity—An Analysis', *The Oil Drum* (6 April 2010) <http://www.theoildrum.com/node/6345#more> [accessed March 2012]

[561] In ibid

[562] Ibid

[563] Ibid

b) Reserve estimates of NNRs are varied and uncertain, but mining lower grade quality of metals and minerals is a clearer concern for meeting demand

A 2011 report from UNEP's International Panel on Sustainable Resource Management on 'Estimating Long-Run Geological Stocks of Metals' finds that estimating the extractable global resource base for the periodic table elements is a "work in progress" with much missing data.[564] Despite this, they are confident in concluding that the likelihood of discovering further rich, mineable resource stocks near to the Earth's crust surface is low since most of these locations have already been explored. Bearing in mind the resultant reality of declining grades of minerals, the report seeks to discover the "abundance spectrum" of these minerals globally to enable long-term planning for the sustainability of metal supplies.[565] Since current figures, where they exist, are government-produced, not independently verified, and limited in the range of materials they are available for, UNEP point to the need for establishing lower and upper reserve limits for all metals and likely probability distributions, to include data on ore grade, depth and amount available. They find that USGS data is the best available, but still limited in its scope and reliability.

A report from the UK House of Common's Committee on Science and Technology on 'Strategically Important Metals', also found that estimated reserves of strategic metals vary and are uncertain.[566] At current consumption rates, for example, indium reserves are stated to last for 13 years and platinum, for 360 years.[567] However, a contrasting study, conducted by a geologist at the University of Cardiff, found that if all 500 million vehicles in use today were to be refitted with fuel cells, global resources of platinum would run out in a mere 15 years[568], demonstrating that future growth trends will have a significant role to play in determining the depletion rate of these key resources. An infographic published by the *New Scientist* alongside an article exploring 'Earth's natural wealth: an audit' gives a crude depiction of how many years key minerals would last if the global population were to consume both at today's rate and then at half the rate of the average US citizen today, based on USGS data and UN population statistics, but without accounting for increases in demand due to technological advances and assuming that current production equals consumption:

[564] T.E. Graedel et al., 'Estimating Long-Run Geological Stocks of Metals', *United Nations Environment Programme International Panel on Sustainable Resource Management: Working Paper* (April 2011) <http://www.unep.org/resourcepanel/Portals/24102/PDFs/GeolResourcesWorkingpaperfinal040711.pdf> [accessed March 2012] p. 1

[565] Ibid, p. 6

[566] Strategically Important Metals - Science and Technology Committee, 'Trade and geopolitics', *Parliamentary Business: Publications and Records* (17 May 2011)

[567] Ibid

[568] David Cohen, 'Earth's natural wealth: an audit', *New Scientist,* Issue 2605 (23 May 2007) <http://www.science.org.au/nova/newscientist/027ns_005.htm> [accessed March 2012] pp. 34-41

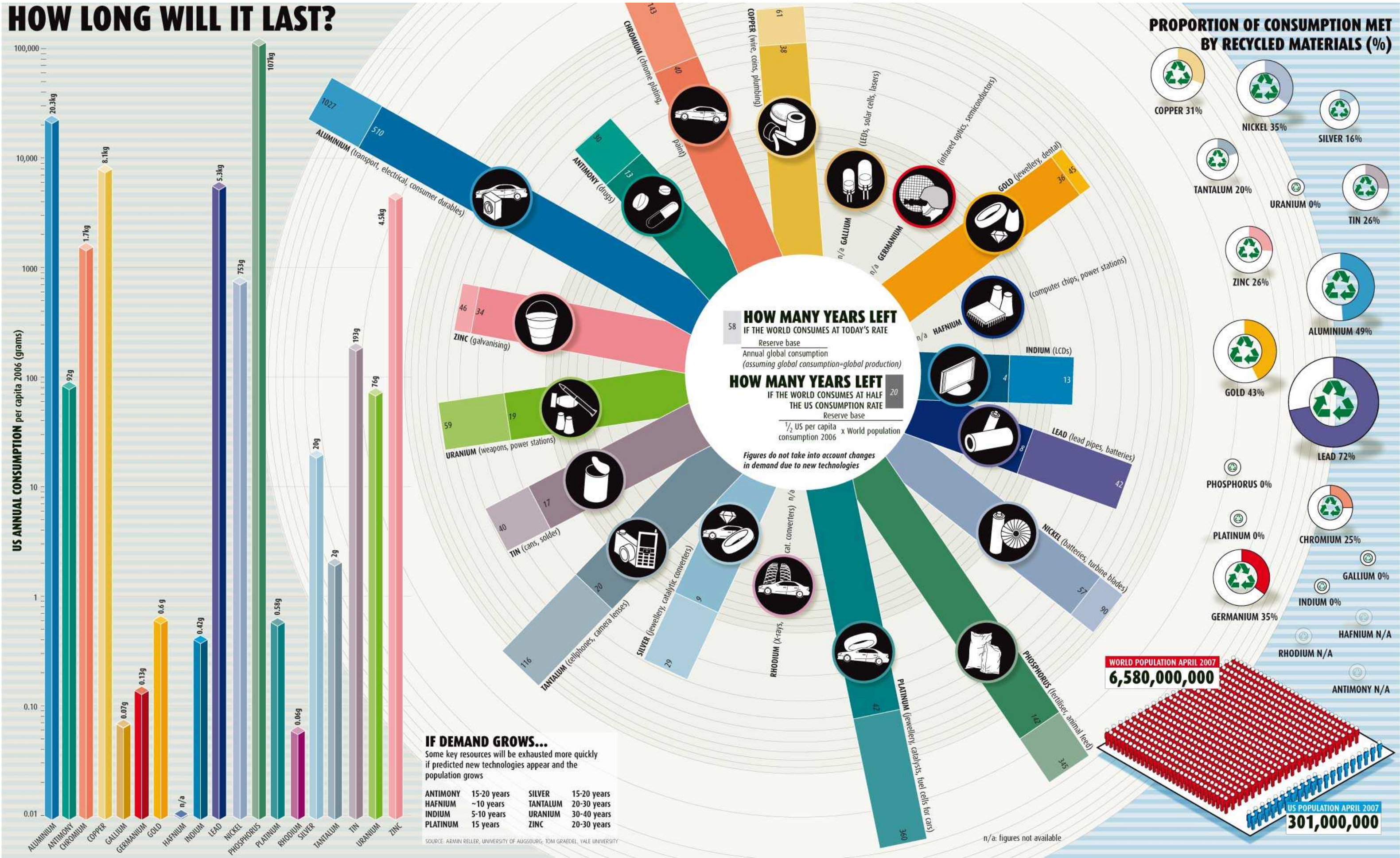

Figure 44: How Long Will It Last? [582]

This somewhat rough picture gives at least a sense of the pressure points the world is facing in terms of the current status of mineral reserves. It may well be that, as the UK House of Commons Select Science and Technology Committee concludes, “Most strategic metal reserves are unlikely to run out over the coming decades. In practice, improved technology, the use of alternative materials and the discovery of new reserves are likely to ensure that strategic metals are accessible.”[569] However, they do acknowledge that were this to happen it would result in “significant environmental and monetary cost associated with the exploitation of lower grade minerals.”

A study by the University of Monash on the 'Sustainability of Mining in Australia' examines the 'economic resource base' of a number of minerals in the mining sector, finding that over the long-term, thanks to technological advances, most minerals have been maintained at reasonable reserve-to-production ratios over the 20th century globally.

Table: 2007 Economic Resources, Production and Resources-Production Ratio[570]

Mineral	2007 Production	Economic Resources	Resources-to-Production
Bauxite	62.40 Mt	6,200 Mt	99 years
Black Coal	420.1 Mt	38,900 Mt	93 years
Brown Coal	65.61 Mt	37,300 Mt	569 years
Copper	880 kt	59.3 Mt	67 years
Diamonds	19.22 Mcarats	425 Mcarats	16 years
Gold	245.04 t	5,839 t	23.8 years
Ilmenite	2.24 Mt	221	99 years
Iron Ore	271.0 Mt	20,300 Mt	75 years
Manganese Ore	4.35 Mt	164 Mt	38 years
Lead	636 kt	23.3 Mt	37 years
Nickel	184 kt	25.8 Mt	140 years
Rutile	312 kt	23.1 Mt	74 years
Uranium	10.15 kt	1.465 Mt	144 years
Zinc	1,421 kt	42.5 Mt	30 years
Zircon	600 kt	39.0 Mt	65 years

However, the figures above assume 2007 consumption levels to remain constant. To meet rising demand, discoveries and production levels will need to increase, which is also going to be more difficult as ore grade quality is generally declining while mines are getting deeper. The author of the study explains that the key question is not the finite nature of the resource but the point at which it is likely to still be considered 'economic' as well as associated environmental and social costs, which are expected to rise per unit of production due to intensified use of energy and water associated with deeper extraction and increased pollution.

Low grades have been denting mineral production in recent years. In November 2011, metals strategist Stephen Briggs at BNP Paribas, has said that the average grade of copper ore has been declining for the past decade or so, resulting in a 24% year-on-year drop in copper production for the company.[571] Global iron ore grades are also declining due to increased

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[569] Strategically important metals – Science and Technology Committee, ‘Conclusions and Recommendations’, *Parliamentary Business: Publications and Records* (17 May 2011) <http://www.publications.parliament.uk/pa/cm201012/cmselect/cmsctech/726/72610.htm> [accessed March 2012]

[570] In Dr Gavin M. Mudd, *The Sustainability of Mining in Australia* (Monash University, 2009) (Reproduced with permission.)

[571] Kitco News, 'Analysts Look For Decline In 2011 Global Copper-Mine Production', *Forbes* (11 November 2011) <http://www.forbes.com/sites/kitconews/2011/11/11/analysts-look-for-decline-in-2011-global-copper-mine-production/> [accessed March 2012]

production in low-grade regions and lack of new supply in high-grade regions, according to Anglo American.[572]

Similarly ore grades for nickel, used primarily in the production of steel, are also declining, with greater future reliance on the use of 'laterite' nickel, which accounts for 73% of global nickel resources. Sulphide nickel resources, which contain higher-grade ores, are running down, thus mining companies are increasingly turning to laterite supplies to meet future demand, which contain lower grades of nickel and are more costly to mine.[573] A report from Global Mining Finance finds that as a result future capital intensity of mining nickel will be double what it was a decade ago.[574] The following graph from a UNEP report shows declining ore grades for both nickel and copper mines between 1885 – 2010:

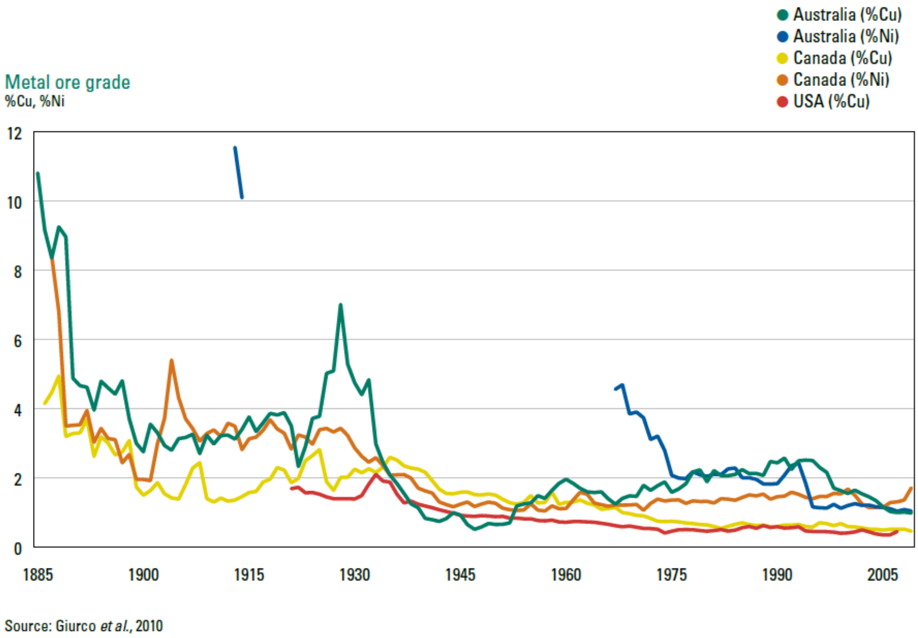

Figure 45: Ore grades of nickel and copper mines, 1885–2010[575]

The *Limits to Growth 30-Year Update* highlights the correlation between declining ore grades and increasing energy inputs in extraction in the case of iron and aluminium production:

[572] Anglo American, *Anglo Ferrous Metals – Minas Rio Project* (7 October 2009) <www.investis.com/anglo_report_pdf/AFM-Minas-Rio-FINAL.pdf> [accessed March 2012]
[573] Global Mining Finance, 'Commodity Focus: Nickel', *Global Mining Finance* (2011) <www.globalminingfinance.com/documents/GMF-2011-Nickel.pdf> [accessed March 2012] p. 92
[574] Ibid
[575] In UNEP, *Decoupling natural resource use and environmental impacts from economic growth*, (Switzerland: UNEP, 2011), p. 24

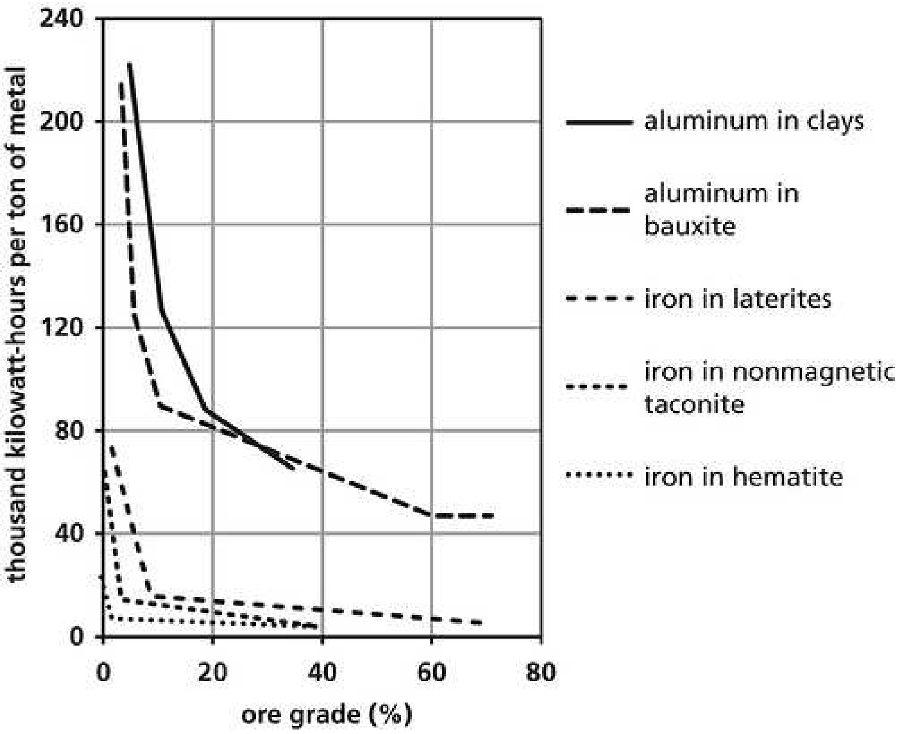

Figure 46: Energy required to produce pure metal from ore[576]

Declining ore grade requires a greater tonnage of rock to be lifted per unit of output, a more intensified extraction process involving greater levels of compression or material throughput, and larger tailing piles to manage. Indeed, the UNEP report on resource decoupling finds that about three times more material needs to be moved for the same ore extraction than a century ago, with corresponding increases in land disruption, water impacts and energy use.[577] André Diederen, senior research scientist at TNO, Holland, explains that all of this requires more energy, and therefore, although in the past reserves have been able to be revised upwards as they have become economically feasible to mine thanks to the abundance of cheap and available fossil fuels, in the future, this paradigm will no longer be valid as energy faces increasing scarcity and rising costs. He believes this casts severe doubts on the future availability of mineral reserves.[578]

The increase of waste output from dealing with lower ore grades is also an issue. Tailings – ground rock and process effluents left after mining – are the single most important source of environmental impact from the mining sector. Over the last century the volumes of tailings being generated has grown dramatically as the demand for minerals and metals has increased and lower and lower grades of ore are being mined. In the 1960s tens of thousands of tonnes of tailings were produced each day; by 2000 this figure increased to hundreds of thousands of tonnes.[579] Waste increases carry cost penalties both in terms of direct disposal or storage costs and in opportunity costs, where the more capital spent on

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576 In Donnella Meadows, Jorgen Randers and Dennis Meadows, *Limits to Growth* (London: Earthscan, 2010) (Reproduced with permission.) p.147

577 UNEP, *Decoupling natural resource use and environmental impacts from economic growth*, (Switzerland: UNEP, 2011)

578 André Diederen, 'Minerals scarcity: A call for managed austerity and the elements of hope', *The Oil Drum* (4 May 2009) <http://www.theoildrum.com/node/5239> [accessed March 2012]

579 J. Engels and D. Dixon-Hardy, 'What are tailings? They Nature and Production', *Tailings.info* <http://www.tailings.info/tailings.htm> [accessed March 2012]

dealing with waste and resource production means less is available for other economic investments, all else being equal.

c) **Geographical spread of commodity resources is uneven causing supply risks, particularly in the face of the growth of clean energy technology deployment**

As we have seen above, 97% of Rare Earth Metals are mined in China. With the country imposing export quotas causing price rises of between 300 – 700% in 2010[580], the risks of monopolies and oligopolies on strategic materials is apparent. Other instances of such market dominance exist for metal resources, for example, Brazil produces 92% of niobium, South Africa and Kazakhstan account for 62% of chromium[581] and the DRC is expected to be extracting 54,000 tonnes per year of cobalt, used in manufacturing mobile phone technology, over the next few years, with current global demand at 60,000 tonnes.[582] European alarm over minerals shortages, sounded by the publication of a European Commission study published in June 2010, in which it was identified that the EU faced shortages of 41 critical raw materials used in mobile and low-carbon technologies, was mainly caused by the fact that production of these materials is concentrated in just four countries: Brazil, China, the DRC and Russia.[583] The image below, also by the *New Scientist*, gives a snapshot of the uneven global distribution of resources:

[580] United States Department of Energy, *Critical Materials Strategy* (Dec 2010) <http://energy.gov/sites/prod/files/edg/news/documents/criticalmaterialsstrategy.pdf> [accessed March 2012] p. 92

[581] 'Strategically important metals', *Parliamentary Business* (17 May 2011)

[582] Natasha Odendaal, 'DRC cobalt increase driving technology', *Mining Weekly* (2 September 2011) <http://www.miningweekly.com/article/drc-cobalt-increase-driving-technology-2011-09-02> [accessed March 2012]

[583] James Kanter, 'Europe Sounds Alarm on Minerals Shortage', *The New York Times* (16 June 2010)

Figure 47: Where the Minerals Are[584]

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[584] In David Cohen, 'Earth's natural wealth: an audit', *New Scientist,* Issue 2605 (23 May 2007) (Reproduced with permission.)

One particular issue looming on the horizon is the anticipated growth in demand for many of these minerals due to the push towards a low-carbon, high-tech economy. For example, gallium, indium, selenium, tellurium and high purity silicon are needed to make photovoltaic panels. 'Permanent' magnets use neodymium and dysprosium, among other rare-earth elements, for use in wind turbines. High-capacity batteries for hybrid and electric vehicles require zinc, vanadium, lithium and rare earth elements too, while platinum group minerals are needed for fuel-cells. As part of efforts to advance a "clean energy economy", the US Department of Energy published an updated 'Critical Materials Strategy' in December 2011 to assess the use of these materials in key low-carbon technologies and examine the risks to meeting this challenge posed by the vulnerability of many of these elements due to their location, exposure to supply shocks and lack of suitable substitutes.[585] The UK Government has published a similar strategy[586]. The table below provides an overview of key materials used in leading clean energy technologies:

	Photovoltaic Films	Wind Turbines	Vehicles		Lighting
MATERIAL	*Coatings*	*Magnets*	*Magnets*	*Batteries*	*Phosphors*
Indium	●				
Gallium	●				
Tellurium	●				
Dysprosium		●	●		
Praesodymium		●	●	●	
Neodymium		●	●	●	
Lanthanum				●	●
Cobalt				●	
Manganese				●	
Nickel				●	
Lithium				●	
Cerium				●	●
Terbium					●
Europium					●
Yttrium					●

Figure 48: Materials in Clean Energy Technologies and Components[587]

The study is particularly concerned with the potential supply and demand imbalances that could arise from anticipated growth in deployment of clean energy technology options, over and above the potential demand generated by non-clean technologies such as flatscreen televisions, mobile phone devices and polishing powders. It comes up with a range of hypothetical demand scenarios based on low, medium or high-level deployment rates, including wind, battery, solar and fluorescent lighting technology. Taking wind turbines and electric vehicles as an example, both requiring the use of magnet technology, the report analyses key material use trajectories between 2010 - 2025, finding that significant supply gaps emerge as soon as 2015 under high-penetration scenarios for neodymium and dysprosium. For wind technology, the report's deployment trajectories are based on the

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[585] United States Department of Energy, *Critical Materials Strategy* (Dec 2010)
[586] UK Department for Business, Innovation & Skills & UK Department for Environment, Food and Rural Affairs, *Resource Security Action Plan: Making the most of valuable materials* (March 2012)
[587] In United States Department of Energy, *Critical Materials Strategy* (Dec 2011) <http://energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf> [accessed March 2012] p. 14 (Reproduced with permission.)

IEA's 2010 World Energy Outlook projections for onshore and offshore wind, with the 'low' rate based on the 'Current Policies scenario', and the 'high' on the '450 scenario' aimed at cutting greenhouse gas emissions. For electric vehicles, trajectories are based on the IEA's 2010 'Energy Technology Perspectives', with 'low' deployment based on the '2010 baseline scenario' for HEVs, PHEVs, and EVs, and 'high' on the 'BLUE Map Scenario', also designed to dramatically cut emissions. The below graph shows the range for future neodymium demand and supply, which includes supply estimates for 2010, for 2010 plus two individual mines that are close to scaling up operations, as well as an estimate for 2015 supply.

The report concludes that the accelerated commercialisation and deployment of clean energy technologies face considerable risks of supply-demand imbalances from outpacing of new mining projects and geopolitical vulnerabilities that could lead to increased price volatility and supply chain disruption. As a result the report recommends that the US begin the work of addressing these challenges by encouraging a globally diverse supply chain, identifying potential substitutes and improving recycling and reuse where possible. Indeed, in the case of neodymium this may well prove to be prudent. China currently supplies most of the world's neodymium. However, it plans to build 330GW worth of wind generators, requiring 59,000 tonnes of the mineral, which is more than the country's entire annual output.[588] These cases indicate, a scientist at the Colorado Geological Survey told the Geological Society of America in November 2010, that the growth of alternative energy will likely trigger international trade wars.[589]

[588] Emma Woollacott, 'Shortage of alternative energy minerals will trigger trade wars', *TG Daily* (1 November 2010) <http://www.tgdaily.com/sustainability-features/52283-shortage-of-alternative-energy-minerals-will-trigger-trade-wars#0_undefined,0_> [accessed March 2012]
[589] Ibid

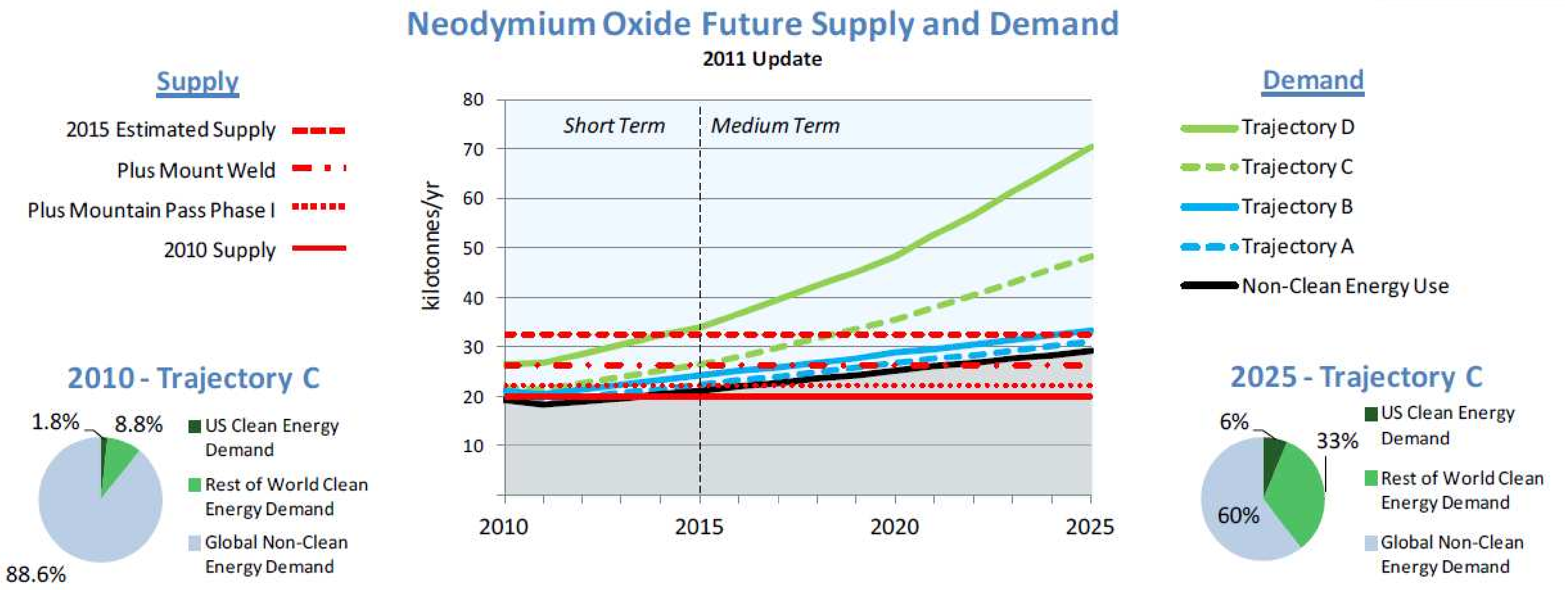

Figure 49: Neodymium Oxide future supply and demand (2011 Update)[590]

[590] In ibid p. 90 (Reproduced with permission.)

d) **Increasing reuse and recycling is slow**

According to UNEP's 2011 'Recycling Rates of Metals: A Status Report', the first attempt to gather accurate and consistent information about the extent to which metals are collected, processed and reused in new products, recycling rates for many metals are currently far lower than their potential.[591] Less than one-third of 60 metals studied have an end-of-life recycling rate above 50% and 34 elements are below 1% recycling, even though many of them are crucial to clean technologies.[592] Thomas Graedel, Professor of Industrial Ecology at Yale University, warns that "By failing to recycle metals and simply disposing of these kinds of metal, economies are foregoing important environmental benefits and increasing the possibility of shortages. If we do not have these materials readily available at reasonable prices, a lot of modern technology simply cannot happen."[593]

In the face of soaring prices for metals and minerals due to supply chain constraints, a number of countries are heeding this warning, increasingly emphasising the reuse and recycling of these elements to ensure a reliable and accessible supply. Japan has made the recycling of rare earth elements compulsory.[594] In January 2011 the European Union announced that it was considering similar measures, to be mainly applied to the automobile and electronics industries.[595] In July 2011, the US government announced its 'National Strategy for Electronics Stewardship' to improve its management of discarded and used materials in electronic equipment with the aim of both protecting the environment and conserving valuable resources.[596] The US EPA has committed $2.5 million towards a project that will work with international partners to track US electronic waste flows in a bid to find solutions to enhancing recycling efforts.[597]

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591 T.E Graedel et al., *Recycling Rates of Metals: A Status Report*, United Nations Environment Programme (2011) <http://www.unep.org/resourcepanel/Portals/24102/PDFs/Metals_Recycling_Rates_110412-1.pdf> [accessed March 2012]

592 Ibid

593 'Dramatically Raising Low Metal Recycling Rates Part of Path to Green Economy', *ScienceDaily* (26 May 2011) <http://www.sciencedaily.com/releases/2011/05/110526091756.htm> [accessed March 2012]

594 Roman Baudzus, 'EU is Paving the Way for New Law to Recycle Rare Earth Minerals', *Gold Money* (31 January 2011) <http://www.goldmoney.com/gold-research/eu-is-paving-the-way-for-new-law-to-recycle-rare-earth-minerals.html> [accessed March 2012]

595 Ibid

596 White House Council on Environmental Quality, US Environmental Protection Agency, General Services Administration, *National Strategy for Electronics Stewardship*, Interagency Taskforce on Electronics Stewardship (20 July 2011) <http://www.epa.gov/waste/conserve/materials/ecycling/taskforce/docs/strategy.pdf> [accessed March 2012]

597 Clay Dillow, 'A New International Project Aims to Track U.S. Electronic Waste for Recycling', *Popsci* (5 March 2011) <http://www.popsci.com/science/article/2011-05/new-international-project-aims-track-us-electronic-waste-recycling> [accessed March 2012]

4.7.2 When will the constraint occur?

	Commodity	World Peak Estimate	Source	Date of Prediction
Base Metals	**Copper**	"High probability" of permanent global supply shortfalls by 2030	Chris Clugston, The Oil Drum[598]	2010
		Production in US – 1998; Chile production – 2007; Peru – 2025; China – 2020; Indonesia – 2001; Australia – 2030 (optimistic); Canada – 1974; Russia – peaking now. World = 2020	Jean Laherrère, The Oil Drum[599]	2010
		Seeing the approach of peak copper	Dr. Les Coleman, University of Melbourne[600]	2009
		Many large copper mines to be exhausted between 2010 – 2015	Andrew Leonard, *Salon*[601]	2006
		To run out within 25 years	Lester Brown, Earth Policy Institute[602]	2006
		"…virgin stocks of several metals (incl. copper) appear inadequate to sustain the modern ''developed world'' quality of life for all Earth's peoples under contemporary technology."	R. B. Gordon et al, Yale University[603]	2006
	Iron Ore	Iron ore supplies already "at their limit"	BHP Billiton CEO, Marius Kloppers[604]	2011

598 Chris Clugston, 'Increasing Global Non-renewable Natural Resource Scarcity', *The Oil Drum* (6 April 2010)
599 Jean Laherrère, 'Copper Peak', *The Oil Drum* (31 March 2010) <http://www.theoildrum.com/node/6307> [accessed March 2012]
600 Dr. Les Coleman, ''Peak copper', not peak oil, the real commodity concern', *The Melbourne Newsroom* (16 December 2009) <http://newsroom.melbourne.edu/studio/ep-60> [accessed March 2012]
601 Andrew Leonard, 'Peak copper?', *Salon* (2 March 2006) <http://www.salon.com/2006/03/02/peak_copper/> [accessed March 2012]
602 Lester Brown, *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble* (New York: W.W. Norton, 2006) p. 109
603 R. B. Gordon, M. Bertram, and T. E. Graedel, 'Metal Stocks and Sustainability', *Mindfully.org* (31 January 2006) <http://www.mindfully.org/Sustainability/2006/Metal-Stocks-Gordon31jan06.htm> [accessed March 2012]

		No need to worry about peak iron ore	Gavid Mudd, Monash University, Australia[605]	2011
		"High probability" of permanent global supply shortfalls by 2030	Chris Clugston, The Oil Drum[606]	2010
		Peak iron ore / peak metals "not on horizon"	Rio Tinto[607]	2010
		Iron ore could run out in 64 years	Lester Brown, Earth Policy Institute[608]	2006
	Zinc	"Very high probability" of permanent global supply shortfalls by 2030	Chris Clugston, The Oil Drum[609]	2010
		2012	Credit Suisse[610]	2010
		Severe supply shortages by 2010	Dr. Harlan Meade, President & CEO of Pacifica Resources Ltd and Yukon Zinc Corp.[611]	2006
Rare Earth Metals	**Gallium**	2002 according to USGS data; 2000 according to logistic fit of data	Ugo Bardi and Marco Pagani, The Oil Drum[612]	2007
	Indium	"High probability" of permanent global supply shortfalls by 2030	Chris Clugston, The Oil Drum[613]	2010
		Will run out in 10 years	Armin Reller, University of Augsburg, Germany[614]	2007

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[604] Frik Els, 'Iron ore price scales $180/tonne to within reach of record highs', *Mining.com* (25 August 2011)

[605] Gavid Mudd, Mohan Yellishetty, 'The Boom: Iron ore and Australia', *The Conversation* (29 July 2011) <http://theconversation.edu.au/the-boom-iron-ore-and-australia-1847> [accessed March 2012]

[606] Chris Clugston, 'Increasing Global Non-renewable Natural Resource Scarcity', *The Oil Drum* (6 April 2010)

[607] Eric Finlayson, 'Future developments and supply challenges for the iron ore sector', *Rio Tinto* (5 October 2010) <http://www.riotinto.com/documents/Media-Speeches/RT_CommoditiesWeekEF_5Oct10.pdf> [accessed March 2012]

[608] Lester Brown, *Plan B 2.0*, (New York: W.W. Norton, 2006) p. 109

[609] Chris Clugston, 'Increasing Global Non-renewable Natural Resource Scarcity', *The Oil Drum* (6 April 2010)

[610] Michael Shillaker et al, 'Metals/Mining update: Think zinc!...The new iron ore?', *Credit Suisse: Equity Research* (12 Jan 2010)

[611] Myra P. Saefong, 'Zinc supplies are quietly running out', *Market Watch* (15 December 2006) <http://www.marketwatch.com/story/zinc-supplies-are-quietly-running-out> [accessed March 2012]

[612] Ugo Bardi and Marco Pagani, 'Peak Minerals', *The Oil Drum* (15 October 2007) <http://www.theoildrum.com/node/3086> [accessed March 2012]

[613] Chris Clugston, 'Increasing Global Non-renewable Natural Resource Scarcity ', *The Oil Drum* (6 April 2010)

		Lack of indium will mean that its “substantial contribution” to future production of solar cell technology will be very limited	René Kleijn, Leiden University, Netherlands[615]	2007
	General	Concern for general supply gaps of “critical materials” by 2015	US Department of Energy[616]	2010
		EU concerned over shortages 0f 14 “critical raw materials”	European Commission[617]	2010

[614] Robin Moroney, 'A Metal Scare to Rival the Oil Scare', *The Wall Street Journal* (25 May 2007) <http://blogs.wsj.com/informedreader/2007/05/25/a-metal-scare-to-rival-the-oil-scare/> [accessed March 2012
[615] David Cohen, 'Earth's natural wealth: an audit', *New Scientist*, Issue. 2605 (23 May 2007)
[616] United States Department of Energy, *Critical Materials Strategy* (Dec 2011)
[617] James Kanter, 'Europe Sounds Alarm on Minerals Shortage', *The New York Times* (16 June 2010)

4.8 The environment and atmosphere

Another key resource that is the subject of intense political discussion is the ability of the environment and the atmosphere to absorb and process society's waste (whether solid waste, pollution or carbon dioxide emissions).

4.8.1 Finite planetary limits

The idea of finite planetary limits has been given more impetus recently with the work of Johann Rockström of the Stockholm Resilience Centre and Will Steffen of the Australian National University[618]. Together with a group of 26 leading academics in 2009 they developed the framework of nine planetary boundaries. A boundary is defined as the point at which it is possible to take action in time to avoid a 'tipping point' – the limit beyond which the environment goes into a self-reinforcing cycle.

The concept has excited considerable attention and has now been endorsed by the UN and was incorporated into the zero draft of the Rio+20 outcomes document. The framework is presented graphically below.

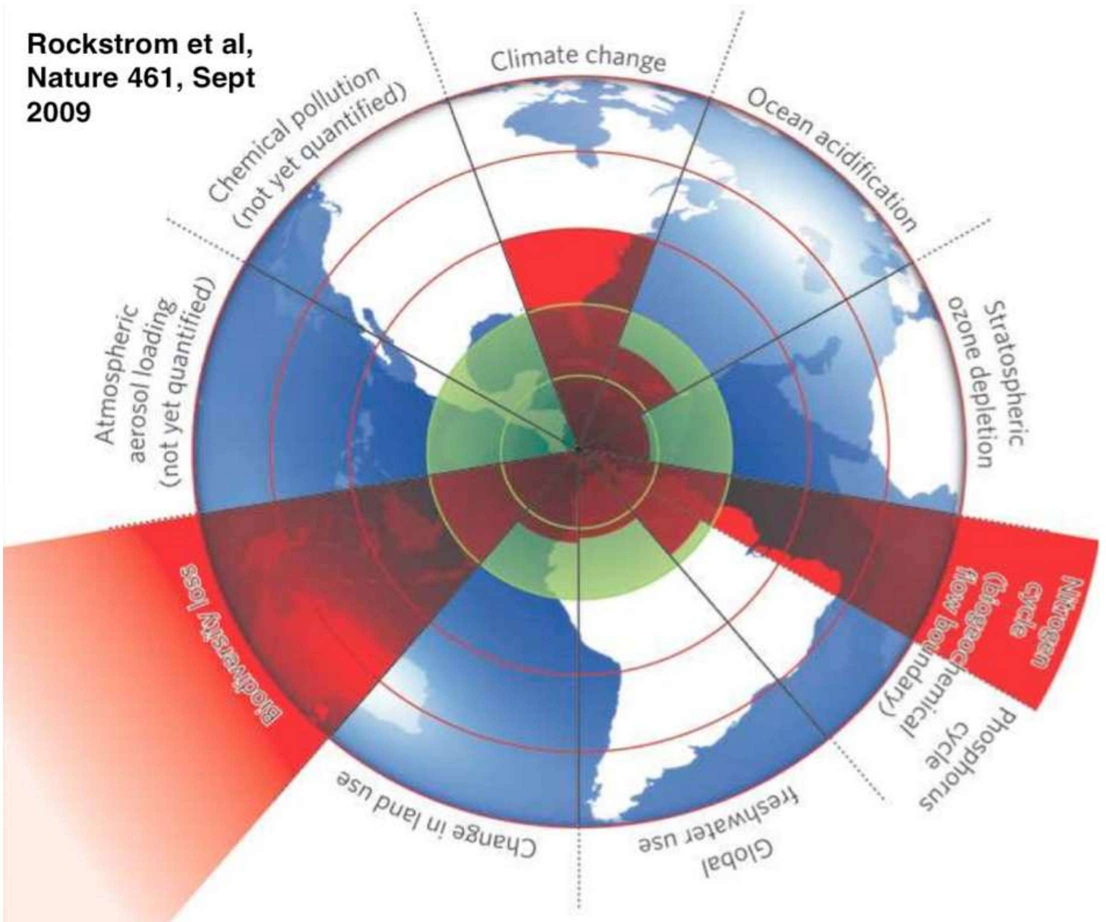

Figure 50: The 9 planetary boundaries of the Stockholm Resilience Centre. [619]

[618] J. Rockström *et al* (2009b) 'A safe operating space for humanity', *Nature* 461, 23 September 2009. Available at: http://www.nature.com/nature/journal/v461/n7263/full/461472a.html

[619] Reprinted by permission from Macmillan Publishers Ltd: Rockstrom et al, *A safe operating space for humanity,* Nature 461, 472-475, 24 September 2009

This concept has been subsequently developed by Kate Raworth to suggest that planetary boundaries can be combined with social boundaries within a single framework.[620] The social foundation forms an inner boundary below which are many dimensions of human deprivation and the environmental ceiling forms an outer boundary. Between these two areas there is a doughnut shaped area *`which represents an environmentally and socially just space for humanity to thrive.'*

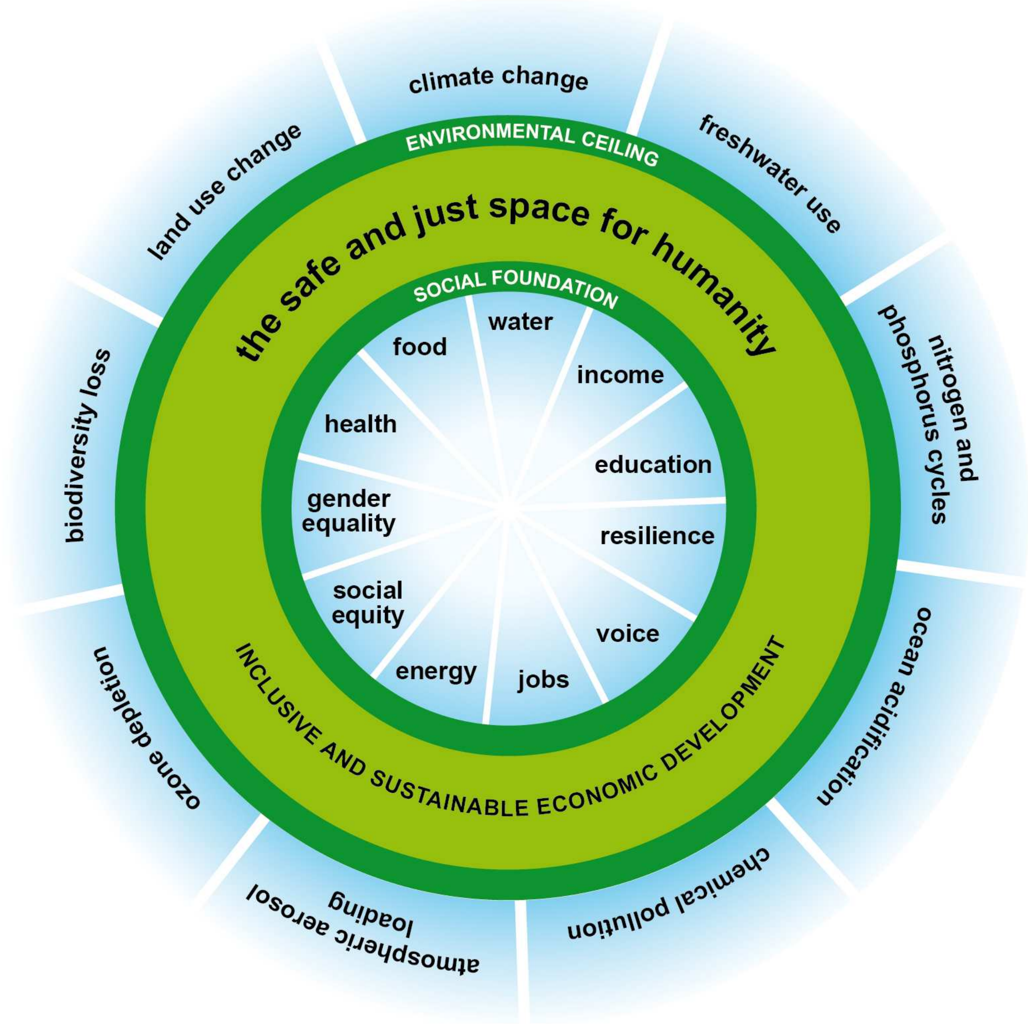

Figure 51: The 11 dimensions of the social foundation developed by Raworth (2012) are illustrative and are based on governments' priorities for Rio+20. The nine dimensions of the environmental ceiling are based on the planetary boundaries

[620] Kate Raworth, *A safe and just space for humanity: can we live within the doughnut?,* Oxfam Discussion Paper, February 2012

4.8.2 Climate change

Greenhouse gases in the atmosphere trap solar energy which results in more energy in the Earth's climate system altering global and local weather systems and shifting the probability distribution of extreme events. Politicians, as part of the United Nations Framework Convention on Climate Change (UNFCCC) process, have agreed to limit global average temperature rise to 2 degrees Celsius above pre-industrial levels. A recent report[621] highlights the impacts that have already been observed as a result of climate change which include:

- Global mean surface temperatures have risen by three-quarters of a degree Celsius (1.3 degrees Fahrenheit) over the last 100 years (1906–2005). Further, the rate of warming over the last 50 years is almost double that over the last 100 years.
- The 16 warmest years on record occurred in the 17-year period from 1995 to 2011.
- Land regions have warmed at a faster rate than the oceans, which is consistent with the known slower rate of heat absorption by seawater.
- Average Arctic temperatures increased at almost twice the global average rate in the past 100 years.
- The thickness and areal extent of Northern Hemisphere snow cover and Arctic sea ice has decreased steadily over the last 30 years, in response to this enhanced polar warming. The last decade (2002-2011) contains the 9 lowest recorded extents of annual minimum Arctic sea ice. 2012 is presently tracking at record low levels.
- The area of glaciers has been decreasing worldwide since the 1960s, as has the thickness of the vast Greenland and Antarctic ice sheets over the past two decades.
- Global average sea level has been rising at a rate of approximately 3 mm (1/8") per year over the past two decades. About half of this rise is due to the expanded volume of sea water under increased temperatures, and the other half to the melting of land ice.
- Regionally, changes in climate variables can be significantly higher or lower than the global average. To give two examples relating to sea-level rise (SLR): (1) in the Southwestern Pacific Ocean, home to numerous low-lying island communities, the rate of SLR is almost 4 times the global mean value; and (2) at two-thirds of measurement stations along the continental shores of the United States, SLR has led to a doubling in the annual risk of what were considered "once-in-a-century" or worse floods.
- Clear evidence has emerged that ecosystems are responding to strong regional warming, e.g., with leaf onset and fruit ripening shifting to earlier in the year and bird and insect populations shifting their ranges poleward.
- Over the past five decades, the frequency of abnormally warm nights has increased, and that of cold nights decreased, at most locations on land. Further, the fraction of global land area experiencing extremely hot summertime temperatures has increased approximately ten-fold over the same period.
- A significant increase in the frequency of heavy precipitation events has been observed in the majority of locations where data are available, and particularly in the eastern half of North America and Northern Europe, where there is a long record of observations.

[621] Solterra Solutions (2012), *Determining the impact of climate change on insurance risk and the global community,* Sponsored by American Academy of Actuaries' Property/Casualty Extreme Events Committee, Casualty Actuarial Society, Canadian Institute of Actuaries & Society of Actuaries

However, the 'world' does not really mind what the climate is doing (it is not a physical limit) and therefore it is a political judgement (or societial) on how much of the likely impacts we are willing to adapt to. This is predominantly an economic and moral discussion.

The economic impact of climate change is the subject of a significant amount of research. The Stern Review[622] identified a number of potential economic impacts based on various climate scenarios. However, the higher likelihood of extreme weather events due to climate change was not well modelled at the time and recent work exploring this, linked to observations of an increase in the number of extreme weather events, indicate that the economic and physical risks could be higher than previously estimated in certain geographic regions[623]. The impact on finance and investment is also the subject of significant research. For example, Silver, Cox, and Garrett, (2010)[624] show that the impacts are split into three categories; primary (the direct climate impact), secondary (the indirect impact of climate change) and tertiary (the resultant impact on economic variables).

The Intergovernmental Panel on Climate Change (IPCC) scenarios point to overshoot in the `safe' level of greenhouse gas emissions and a breach of 2 degrees C temperature rise before 2100 under five of their six scenarios[625]. Only scenario B1 avoids this[626], a world where the emphasis is on local solutions to economic, social and environmental sustainability, with an orientation towards environmental protection and social equity. An IEA report published in November 2011[627] warned that we have only 5 years or less left to radically reduce our energy consumption or change our energy mix in order to avoid dangerous global warming. A PWC report[628] states that *'it's time to plan for a warmer world'* as the annual reduction in carbon intensity required to achieve the 2 degree target per year is over six times higher than our current rate of decarbonisation and there is little indication that this will change.

Case	Temperature change (^{o}C at 2090-2099 relative to 1980-1999)		Sea level rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	Likely range	Model based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations	0.6	0.3-0.9	NA
B1 scenario	1.8	1.1-2.9	0.18-0.38
A1T scenario	2.4	1.4-3.8	0.20-0.45
B2 scenario	2.4	1.4-3.8	0.20-0.43
A1B scenario	2.8	1.7-4.4	0.21-0.48
A2 scenario	3.4	2.0-5.4	0.23-0.51
A1F1 scenario	4.0	2.4-6.4	0.26-0.59

622 Stern (2006), *The Economics of Climate Change*, Cambridge University Press
623 Intergovernmental Panel on Climate Change (2012), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation,* Special Report
624 Silver, N., Cox, M. and Garrett, E (2010) The Impact of Climate Change Overseas on the UK Financial Services Sector. International Dimensions of Climate Change, 7 August, 2010
625 IPCC Fourth Assessment Report, WG1 SPM available at www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf
626 Recent commentators have also noted that as climate change science develops and global climate dynamics are better understood the carbon emission budgets are usually lowered as climate change occurs much more rapidly than predicted in current models.
627 World Energy Outlook 2012, published November 2011
628 PWC, *Too late for two degrees?, Low Carbon Economy Index,* November 2012

The World Bank[629] goes further and states that given the pledges currently made under the UNFCCC by governments the world is on track for a 3.5 to 4 degree rise in temperature by the end of the century and, as even those pledges are not currently being met, a 4 degree rise is more likely. This report states that while the impacts of this rise in temperature remain uncertain the likely risks to food, water, ecosystems and human health are significant.

According to the IEA's World Energy Outlook (WEO) 2011, global investment in energy supply infrastructure of $38 trillion (in year-2010 dollars) is required over the period 2011 to 2035 to meet projected increases in energy demand alone and almost two-thirds of this total investment is in countries outside of the OECD.[630] However, this sets us on a global emissions trajectory consistent with an average temperature increase of 3.5°C. If we are to aim to limit average temperature increases caused by climate change to 2°C this requires additional cumulative investment of $15.2 trillion[631]. Furthermore, delaying action means that for every $1 of investment avoided before 2020, an additional $4.3 will need to be spent after 2020 to compensate for the increased emissions.[632] This is particularly because of two costly knock-on effects of delay; that it increases the amount of capital stock that will need to be retired early, mostly in the power and industry sectors, and dramatically limits the amount of more carbon-intensive infrastructure that can be added in the future.[633]

According to the UNFCCC in 2007 investment in the order of USD 300-400 billion per year will be required by 2030 to fund minimum requirements to reduce emissions and deal with the impacts of climate change.[634] This amounts from 1- 2% of anticipated global investment for all purposes, or less than 1% of global GDP at that date.[635]In 2008, Sir Nicholas Stern doubled his previous estimate of climate change costs from 1% of global GDP to 2%, stating that the pace of climate change was quicker than he had relied upon.[636]

Although estimates are not certain, what is certain is that a large amount of new and additional investment will need to be made if we are to avoid the worst effects of climate change. Current expenditure on new technologies, although increasing, is not yet enough. Bloomberg New Energy Finance (BNEF) estimates that in 2010 a record US$243 billion was invested in the 'clean energy sector', an increase of 30% over 2009 levels.[637] But this is not as much as the IEA WEO 2011 indicates needs to be invested in renewables for their 3.5°C scenario, let alone their 2°C scenario. In the 3.5°C scenario, renewables make up 60% of the

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629 World Bank, *Turn down the heat: why a 4 degree warmer world must be avoided,* November 2012
630 IEA, *WEO 2011* (2011), p. 40
631 Ibid p. 205
632 Ibid
633 Ibid p. 231
634 UNEP FI, *The materiality of climate change: How finance deals with the ticking clock*, A report by the Asset Management Group of UNEP FI (Oct 2009) <http://www.unepfi.org/fileadmin/documents/MatIII_executive_summary.pdf> [accessed March 2012] p. 4
635 Ibid
636 Juliette Jowit and Patrick Wintour, 'Cost of tackling global climate change has doubled, warns Stern', *The Guardian* (26 Jun 2008) <http://www.guardian.co.uk/environment/2008/jun/26/climatechange.scienceofclimatechange> [accessed March 2012]
637 Aled Jones, '*Principles for investment grade policy and projects*', Report produced for the Capital Markets Climate Initiative (CMCI), UK Department for Energy and Climate Change, May 2012

US$675 billion (in year-2010 dollars) per year investment required in the power sector until 2030, even though they make up only half of new capacity.[638]

Of current investment, China made US$54.5 billion – an increase of 39% on the previous year, ranking it first in place of global renewable energy investors.[639] Germany was second, with an investment of $41.2 billion, a 100% increase on the previous year.[640] The US dropped to third place, with US$34 billion, while Brazil, with the world's seventh largest installed clean energy capacity, is sixth in G20 countries and second to China in developing countries, with US$7.6 billion invested that year.[641] The UK and Spain both lagged significantly behind in renewable investment.

The Climate Policy Initiative finds that overall US$97 billion of climate investment is being made to support low-carbon, climate-resilient development activities[642] in developing countries, with US$93 billion going to mitigation measures (such as clean energy investment) rather than adaptation[643]. While this may appear like good news –it is close to the US$100 billion a year promised by the Copenhagen Accord – the report states that in reality a significant share of this finance was already being made prior to the signing of the Accord so does not represent new investment. Out of the estimated US$ 97 billion in global climate funding, on average US$55 billion is provided by the private sector, while only US$21 billion is provided by public budgets.[644] Furthermore, carbon finance represents only a very small share of climate finance (US$2 billion of the US$97 billion), despite high ambitions for carbon markets. Intermediate bilateral and multilateral institutions represent 40% of climate finance activities, with bilaterals distributing about 60% more finance than multilaterals.[645]

In 2010, BNDES, Brazil's development bank, invested over US$3 billion in climate finance, representing about 14% of total climate finance by bilateral financial institutions (BFIs) and the fourth highest behind JICA (Japan), AfD (France) and KfW (Germany).[646]

4.9 Population

The UNDP project that world population will reach 9 billion before 2050 and 10.1 billion by the end of the century according to its latest medium variant prediction.[647] This is partly based on the fact of ageing populations and increasing global life expectancy, which is set to increase from 68 years to 81 by the years 2095 to 2100.[648] However, whether this projection is realised depends largely on the fertility variation. The UNDP's '2010 revision' of its population projections was published with the proviso that "small variations in fertility can produce major differences in the size of populations over the long run. The high projection

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638 IEA WEO 2011, p. 193
639 Aled Jones, '*Principles for investment grade policy and projects'*, Report produced for the Capital Markets Climate Initiative (CMCI), UK Department for Energy and Climate Change, May 2012
640 Ibid
641 Ibid
642 The Climate Policy Initiative, *The Landscape of Climate Finance: A CPI Report* (27 Oct 2011) <http://netzeronyc2020.net/Documents/LandscapeOfClimateFinance177.pdf> p. i [accessed March 2012]
643 Ibid, p. iv
644 Ibid, p. iii
645 Ibid
646 Ibid, p. A1
647 'Global population to pass 10 billion by 2100, UN projections indicate', *UN News Centre* (3 May 2011) <http://www.un.org/apps/news/story.asp?NewsID=38253> [accessed March 2012]
648 Ibid

variant, whose fertility is just half a child above that in the medium variant, produces a world population of 10.6 billion in 2050 and 15.8 billion in 2100. The low variant, whose fertility remains half a child below that of the medium, produces a population that reaches 8.1 billion in 2050 and declines towards the second half of this century to reach 6.2 billion in 2100."[649] In other words, the report highlights that small variations in fertility could lead to major long-term differences in total global population.

Picking up on this theme, Professor of Human Geography at the University of Sheffield, Danny Dorling, argues that progressively diminishing 'baby-boom' peaks and troughs experienced over the past sixty years imply that world population will peak in 2060 at 9.3 billion and then fall to 7.4 billion by 2100 and continue to fall.[650] Progressively lower peaks in population change experienced in 1966, 1986 and 2006 were largely a result of expanding access to contraception worldwide. This trend is likely to continue, thus ever smaller booms on a 20-year cycle (the generation gap) may mean we experience further peaks and then troughs around 2026 and 2046 and so on. Dorling argues that the UNDP projections do not take these fluctuations and cycles –or "changes in change" – into account.[651] The below graph outlines UN demographers' projection of a more stable annual change in population change into the future (thick black line) versus Dorling's projection of repeated peaks and troughs extrapolated from a crude assumption that history has a tendency to repeat itself (dotted line):

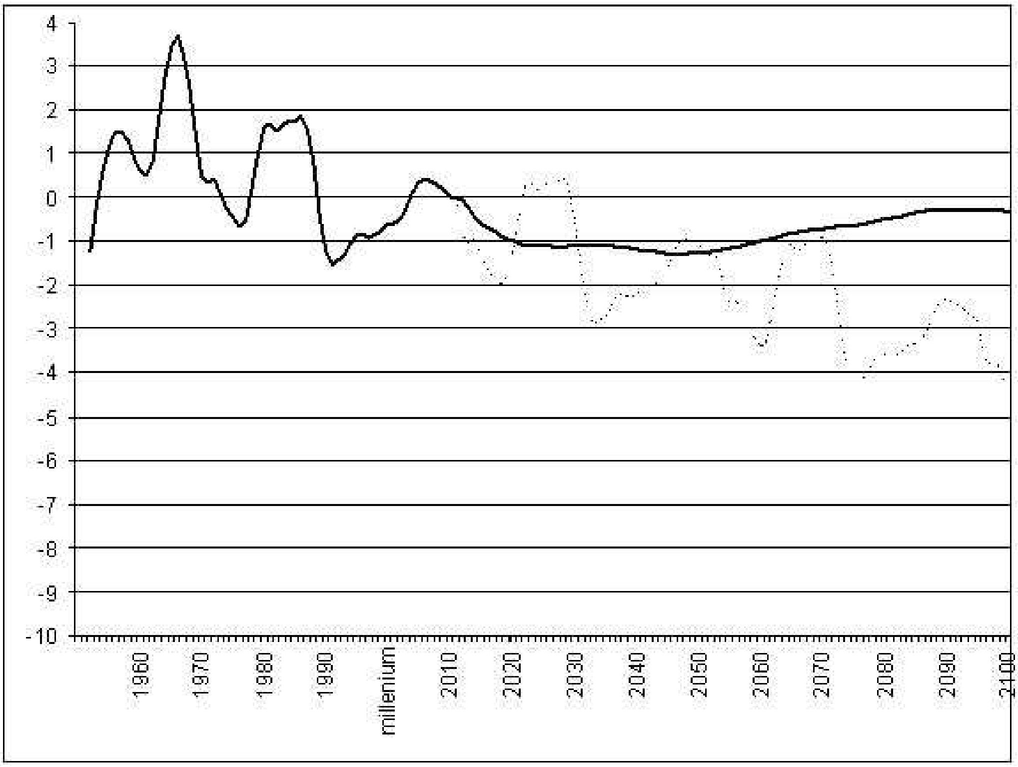

Figure 52: World population estimates and projections annual change in population change (millions)[652]

[649] UNDP in Danny Dorling, 'We're all… just little bits of history repeating (Part 1 – History)', *Significance: Statistics making sense* (2011) <http://www.significancemagazine.org/details/webexclusive/1081285/Were-all___just-little-bits-of-history-repeating-Part-1---History.html> [accessed March 2012]
[650] Danny Dorling, Ibid
[651] Ibid
[652] In ibid

If this type of dynamic in change were to occur, then the implications for the overall trend – as the UNDP states – are significant when accumulated on a global scale and world population will peak and then dip by 2100. Dorling acknowledges this way of projecting on population is crude – however, it highlights the very real fact that trends are far more unstable and susceptible to change and to seemingly unconscious patterns than we may usually predict. As a result we may soon "see the emergence of new regularities in our numbers"[653].

Professor Jorgen Randers also argues that global average fertility rates will be lower than the mid-range projections for the UNDP scenario and therefore global populations will peak well below 9 billion.[654] The key reason for this is that urban populations have traditionally had lower fertility rates than rural populations and with the increased urbanisation of populations the overall trend is therefore towards an accelerated decline in global fertility.

In more advanced economies, the average fertility rate is about 1.7 births — below the replacement level of 2.1 births.[655] In the least developed countries, the rate is about 4.2, with sub-Saharan Africa experiencing a rate of 4.8.[656] According to the UNFPA, however, worldwide, fertility rates have been gradually dropping since the middle of the last century.[657] Indeed, an article in *The Economist* explains that "replacement level of fertility" for the first time ever has (or very soon will have) reached half of humanity; that is that half the world will have a fertility rate of 2.1 or less.[658] This includes countries such as Russia, Japan, Brazil, Indonesia, China and south India.[659] By 2020, the global fertility rate is projected to dip below the global replacement rate for the first time.[660] The rate of declining fertility is speeding up. In the 1970s only 24 countries had fertility rates of 2.1 or less, all of them in the advanced economies. Today, there are over 70 countries in this category in every continent, including Africa. Between 1950 and 2000 the average fertility rate in developing countries fell by half from six to three, while during the same period fertility fell by almost half in Europe.

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[653] Danny Dorling, 'We're all… just little bits of history repeating (Part 2 – The Future)', *Significance: Statistics making sense* (2011) <http://www.significancemagazine.org/details/webexclusive/1082185/Were-all just-little-bits-of-history-repeating-Part-2---The-Future.html> [accessed March 2012]

[654] Jorgen Randers, *2052: A Global Forecast for the Next Forty Years*, (Forthcoming, 2012)

[655] UNFPA, *The State of World Population 2011* (New York: UNFPA, 2011) <http://foweb.unfpa.org/SWP2011/reports/EN-SWOP2011-FINAL.pdf> [accessed March 2012] p. 43

[656] Ibid

[657] Ibid

[658] 'Go forth and multiply a lot less: Lower fertility is changing the world for the better', *The Economist* (29th Oct 2009) <http://www.economist.com/node/14743589> [accessed March 2012]

[659] Ibid

[660] Ibid

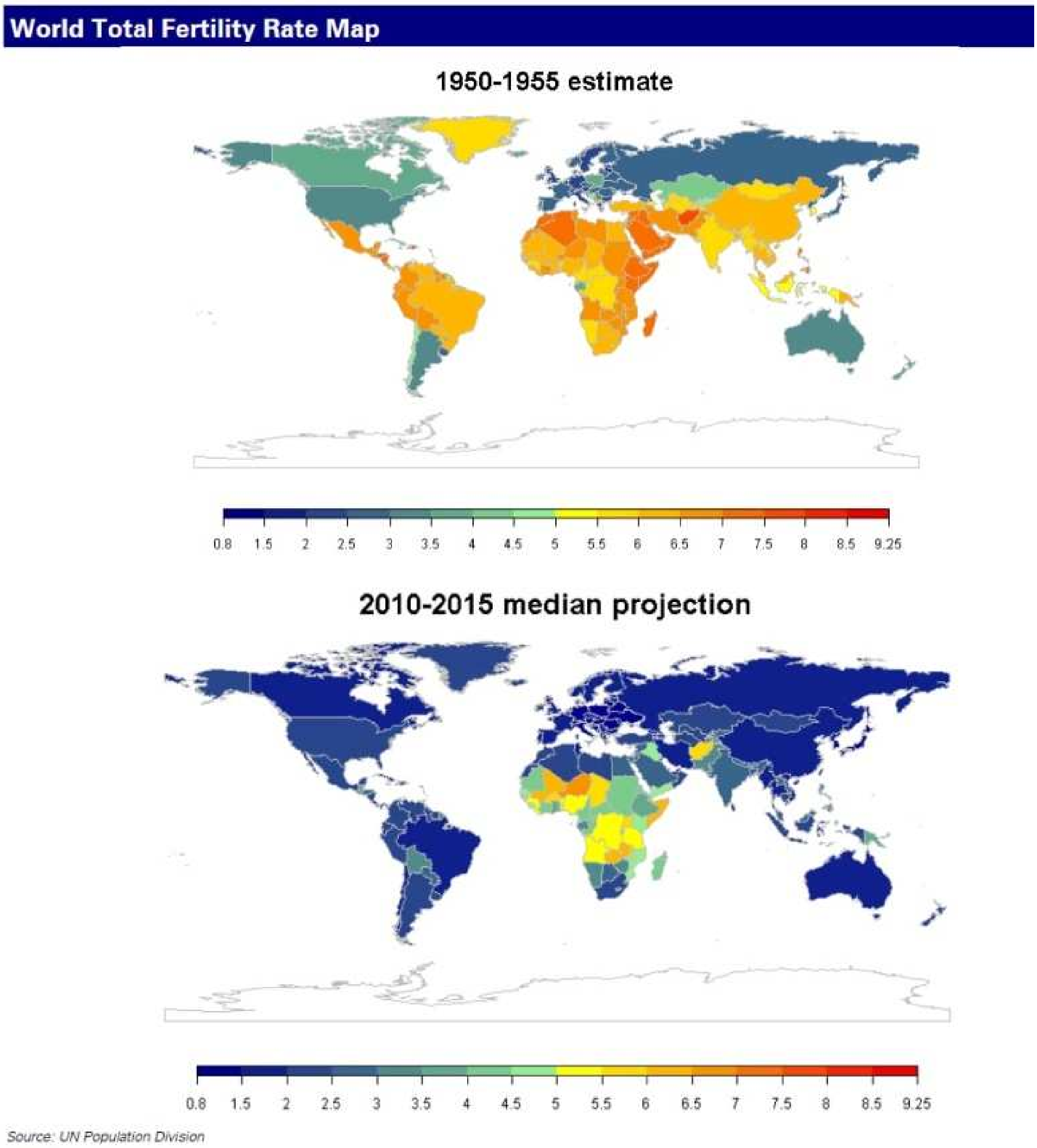

Figure 53: World total fertility rate map (based on UNDP data)[661]

Of course, absolute population numbers can still increase while fertility is on the decline due to inertia in the human system. That is why population numbers are projected to rise before they fall. However, the *rate* of population growth *is* slowing due to falling fertility levels. Whereas in the past the time needed to add 1 billion more people to the human population has rapidly reduced – falling from 32 years to go from 2 to 3 billion, to 12 years to go from 5 to 6 billion – the recent billion also took 12 years while the next billion is forecast, for the first time, to take longer than the previous billion – 14 years.[662] Fertility rates are expected to drop dramatically by 2100 across the globe:

[661] In Sanjeev Sanyal, 'The End of Population Growth', *The Wide Angle*, Deutshce Bank (13 May 2011) <http://www.asiabusinesscouncil.org/docs/EndofPopnGrowth052011.pdf> p. 6 [accessed March 2012]

[662] Sheila Moorcroft, 'Rising to the Challenge of Peak Population', *InnovationManagement.se* (11 Jan 2012) <http://www.innovationmanagement.se/2012/01/11/rising-to-the-challenge-of-peak-population/> [accessed March 2012]

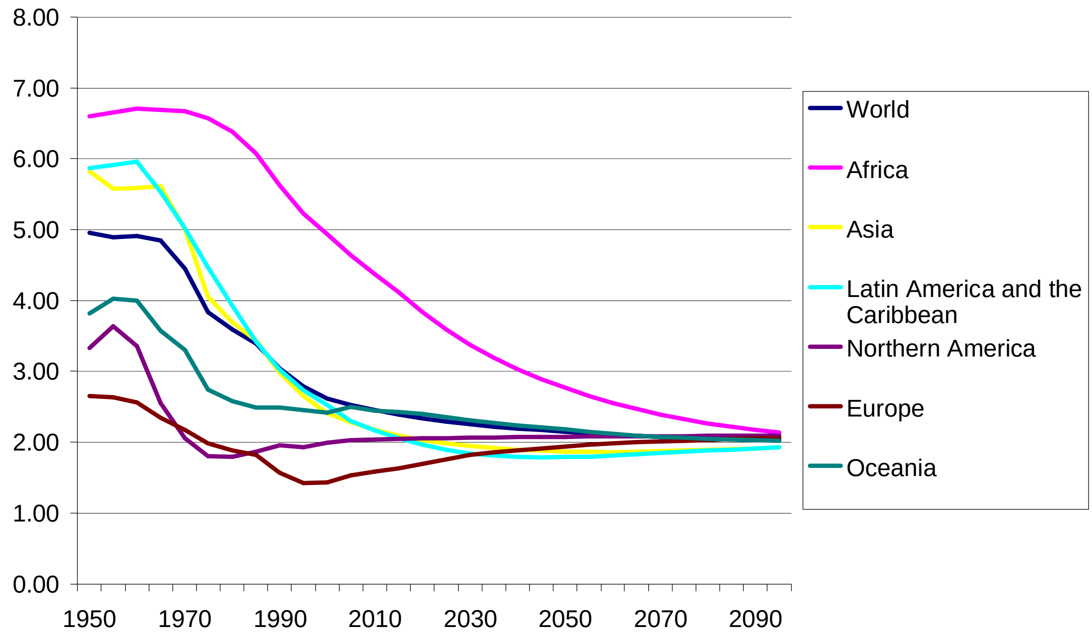

Figure 54: Global fertility rate decline[663]

Peak population growth rates of 2.1% a year occurred in the 1960s and 1970s, with the following drop attributed to the so-called "demographic transition".[664] Of course, the concept of the demographic transition hinges on assumptions made about the negative relationship between economic and social development and birth rates (as wealth increases, birth rates fall). These assumptions are incorporated into projections of when population will peak. However, some researchers have recently started to call these into question when considering the prospect of peak oil and energy price hikes[665] – events that could undermine the economic underpinnings of the demographic transition and begin to pull it into reverse (if no technologies emerge to fill the gap). But other analysts argue, on the other hand, that a decline in global oil supply will actually result in the acceleration of the experience of "overshoot". This is because humanity's use of oil has been a large factor in enabling the vast population boom experienced over the past century, artificially extending the carrying capacity of the earth. If we remove the oil on which we have become dependent (and fail to replace it with an alternative), this population growth trend could be dramatically destabilised and world population "could suffer a precipitous decline"[666].

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[663] In Simon Rogers, 'World population by country: UN guesses the shape of the world by 2100', *The Guardian, Datablog* (26 Oct 2011) <http://www.guardian.co.uk/news/datablog/2011/may/06/world-population-country-un#data> [accessed March 2012]

[664] UNEP, 'One Small Planet, Seven Billion People by Year's End and 10.1 Billion by Century's End', *UNEP Global Environmental Alert Service* (Jun 2011) http://na.unep.net/geas/getUNEPPageWithArticleIDScript.php?article_id=71

[665] Ibid

[666] Graham Zabel, 'Peak People: The Interrelationship Between Population Growth and Energy Resources', *Energy Bulletin* (20 April 2009) <http://www.energybulletin.net/node/48677> [accessed March 2012]

4.10 Capital

The 2007/8 global recession was said by some to be the worst since the Great Depression of the 1930s.[667] It saw the collapse of large financial institutions, the bailout of banks by governments and huge downturns on stock markets worldwide. The "advanced economies" were the worst hit (based on IMF WEO 2010 data):

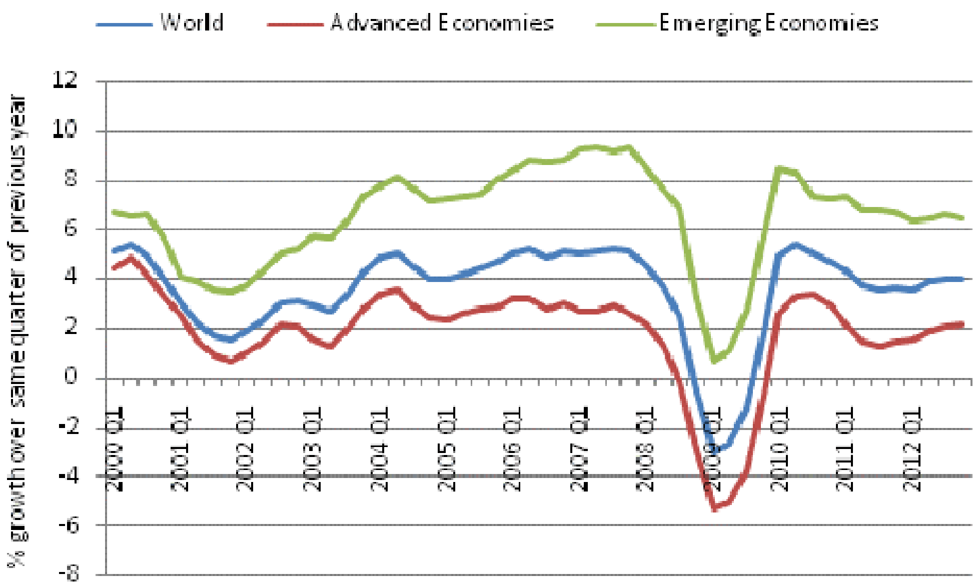

Figure 55: Real GDP growth q1 2000 - q4 2012[668]

Prior to the global recession major economies had financed some public spending through borrowing and as a result of flat or negative growth during the recession, with the exception of a small number of countries such as Canada, this caused a "debt explosion"[669].

Japan now has the highest debt to GDP ratio, with debt amounting to 225.8% of their GDP.[670] At the end of 2010, Greece was found to have a government deficit of 15.4% of GDP and a government debt of 126.8% of GDP[671], and shortly after required a huge bailout from EU members to prevent it from defaulting on its payments. Other countries to be badly

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667 David Pendery, 'Three Top Economists Agree 2009 Worst Financial Crisis Since Great Depression; Risks Increase if Right Steps are Not Taken', *Reuters* (27 February 2009) <http://www.reuters.com/article/2009/02/27/idUS193520+27-Feb-2009+BW20090227> [accessed March 2012]

668 In 'Q&A: The Future of the World Economy', *Euromonitor Global Market Research Blog* (8 October 2011) <http://blog.euromonitor.com/2011/10/qa-the-future-of-the-world-economy.html> [accessed March 2012]

669 Niall Ferguson, 'Fiscal Crises and Imperial Collapses: Historical Perspective on Current Predicaments', Stavros. S. Niarchos Lecture, Peterson Institute for International Economics, Washington, DC (13 May 2010) Available at <http://www.iie.com/events/event_detail.cfm?EventID=152> [accessed March 2012]

670 Mamta Badkar, 'The 15 countries that are buried under the most debt: Japan', *Business Insider* <http://www.businessinsider.com/debt-gdp-world-rankings-2011-04#1-japan-15> [accessed March 2012]

671 Eric van Puyvelde, 'Deficits increase in eurozone and EU', *Europolitics* (November 2010) <http://www.europolitics.info/economy-monetary-affairs/deficits-increase-in-eurozone-and-eu-artb287086-50.html> [accessed March 2012]

affected are Ireland, which some economists have touted as worse off than Greece[672], Italy, with the second highest public debt in the Euro zone to Greece[673], France, the UK and the USA, amongst others. US public debt alone rose by an unprecedented 20% of GDP in less than two years by 2010[674], leading the country to seek to raise its legal limit on its $14.3 trillion debt.[675] FT contributor and CEO of global investment management firm Pimco, Mohamed El-Erian, has described this whole process as "a significant regime shift" undermining the conventional analytical relevance of such distinctions as the divide between advanced and emerging economies.[676] Emerging economies, he states, in many cases currently have better economic prospects and fewer vulnerabilities than do a growing number of so-called 'advanced' nations today.

The traditional developed countries are being surpassed by strong growth trends in emerging markets, which are attracting a growing amount of financial flows. In 2011, while economic growth in the developed world was forecast at 1.6% and 1.9% for 2012, emerging markets were projected to grow 6.4% in 2011 and 6.1% in 2012 – three times as fast.[677] Developing country domestic demand amounted to almost half of global GDP growth in 2010.[678] Three quarters of the increase in high-income country exports during the first half of 2010 were sold to developing countries.[679] Euromonitor International thus describes emerging economies as today's "engines of global growth".[680] As a result they are attracting increasing foreign direct investment (FDI) – a trend that has been apparent since the early 2000s.

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672 Patrick Cooper, 'Ireland worse than Greece, faces financial ruin, say two leading economists', *Irish Central* (May 2010) <http://www.irishcentral.com/news/Ireland-worse-than-Greece-faces-financial-ruin-say-two-leading-economists--94688524.html> [accessed March 2012]

673 Mamta Badkar, 'The 15 countries that are buried under the most debt: Italy', *Business Insider* <http://www.businessinsider.com/debt-gdp-world-rankings-2011-04#8-italy-8> [accessed March 2012]

674 Mohamed El-Erian, 'How to handle the sovereign debt explosion', *Financial Times* (10 March 2010) <http://www.ft.com/cms/s/0/c8655bdc-2c78-11df-be45-00144feabdc0.html#axzz1oY46M800> [accessed March 2012]

675 Dominic Rushe, 'Tensions rise on Capitol Hill as America runs out of money', *The Observer* (3 July 2011) <http://www.guardian.co.uk/business/2011/jul/03/tensions-rise-america-runs-out-of-money> [accessed March 2012]

676 Mohammed El-Erian, 'How to Handle the Sovereign Debt Explosion', *Financial Times*, (10 March 2010)

677 Euromonitor International, 'Q&A: The Future of the World Economy', *Euromonitor Global Market Research Blog* (October 2011) <http://blog.euromonitor.com/2011/10/qa-the-future-of-the-world-economy.html> [accessed March 2012]

678 Paul Barbour, 'Parsing Asia: What New World Bank Reports Say about Investment in the Region', *Worldbank Blog* (23 December 2010) <http://blogs.worldbank.org/category/tags/global-economic-prospects> [accessed March 2012]

679 Dilek Aylut, 'Change in policies toward capital flows: more of this, less of that', *Worldbank Blog* (31 January 2011) <http://blogs.worldbank.org/prospects/archive/201101> [accessed March 2012]

680 Euromonitor International, 'Q&A', *Euromonitor Global Market Research Blog* (October 2011)

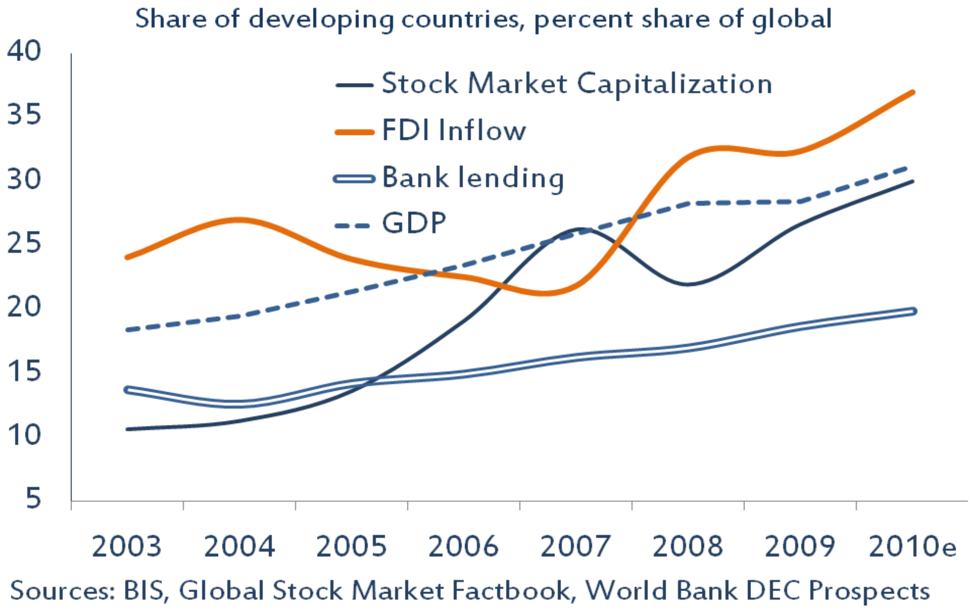

Figure 56: Investors are shifting their asset allocations towards developing countries[681]

In 2010 – for the first time – developing and transitioning economies absorbed close to half of global FDI inflows according to UNCTAD's *World Investment Report 2011*.[682] This was due to the "lingering effects of the crisis and subdued prospects in developed countries".[683] Although FDI flows in 2010 remained overall at about 15% below their pre-crisis average and 37% below their 2007 peak, inflows to China, the largest recipient of FDI in the developing world, climbed by 11% in 2010, to $106 billion.[684] In contrast, FDI inflows to developed countries continued to decline.[685] Europe in particular suffered a sharp drop, while Japan also registered slower FDI flows. This has led UNCTAD to state that emerging economies are the "new FDI powerhouse". Global FDI trends over the period 1980 – 2010 are shown below, clearly demonstrating the way in which transitioning economies are forging ahead:

[681] In Dilek Aylut, 'Change in policies toward capital flows', *Worldbank Blog* (31 January 2011) (Reproduced with permission.)
[682] United Nations Conference on Trade and Development (UNCTAD), *World Investment Report 2011: Non-Equity Modes of International Production and Development* (2011) <http://www.unctad-docs.org/files/UNCTAD-WIR2011-Full-en.pdf> [accessed March 2012]
[683] Ibid
[684] Ibid
[685] Ibid

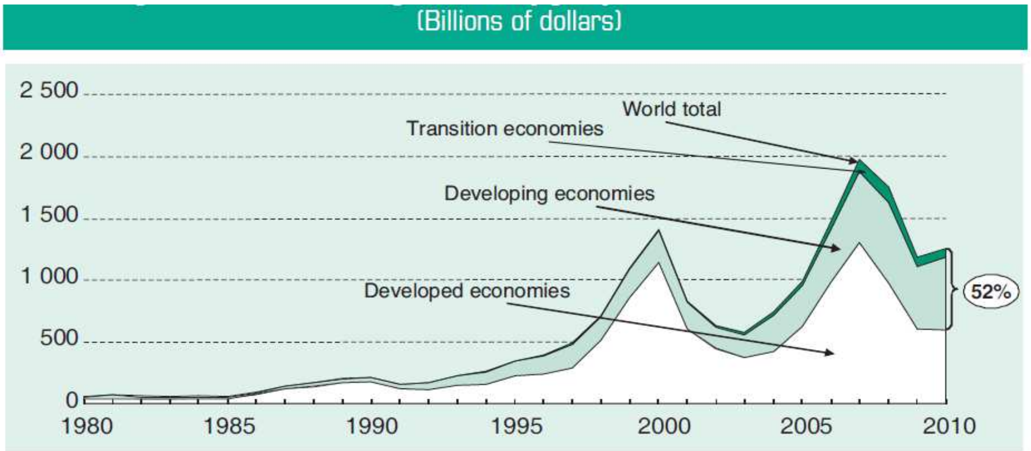

Figure 57: FDI inflows, global and by group of economies, 1980 - 2010[686]

Developing and transition economies also generated record levels of FDI outflows, which increased by 21% between 2009 - 2010, much of it directed to other countries in the South.[687] They now account for 29% of FDI outflows.[688] FDI outflows from advanced economies still dominate, but they are on a downward trend, remaining at half their 2007 peak in 2010.[689] South, East, and South-East Asia as well as Latin America were the drivers behind the increase in developing country FDI outflow. Hong Kong (China) and China are the largest FDI sources, reaching historical heights of $76 billion and $68 billion respectively, overtaking Japan and up more than $10 billion each on 2009 figures.

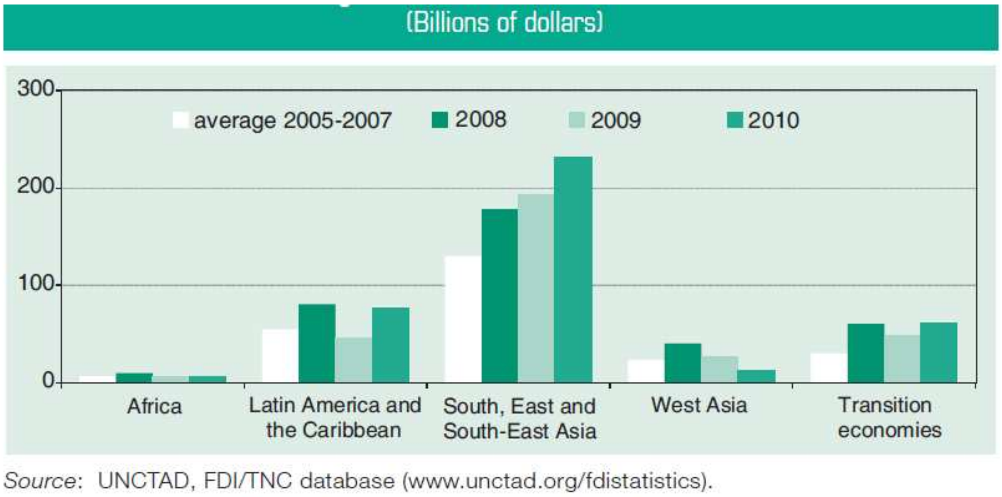

Figure 58: FDI outflows from developing and transition economies, by region, average of 2005 - 2007 and 2008 - 2010[690]

Overall, in 2010, six developing and transition economies were among the top 20 investors, which UNCTAD states is confirmation of the fact that these economies are becoming important investors on the world stage, with this trend only likely to continue in the future.[691]

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[686] In ibid p. 3
[687] Ibid
[688] Ibid
[689] Ibid
[690] In ibid p. 7
[691] Ibid

Pension fund investment in developing countries is also gradually growing. We have already seen how these institutions have been a driving force behind acquisitions of land, in particular in parts of Africa.[692] Pension funds, which hold around $26 trillion worth of assets and comprise almost half of the world economy, are also turning their attention to other asset classes in emerging markets.[693] Marking this significant trend, in August 2011, Japan's government pension fund made its first move into emerging markets.[694] Up until recently, these allocations were only as much as 5% of the global pension cash stock.[695] However, Goldman Sachs has predicted that western investors, who make up the majority of the largest pension fund holders, will increase emerging market equities to 18% of total investments by 2030, while the emerging market share of world indices will rise to 19% from 13%.[696] This is driven by the recent lagging rates of return on developed equities (for example, a loss of 7% in dollar terms on MSCI developed equities since 2006) creating worsening asset-liability mismatches that have left, for example, the US state-pension system over $600 billion short for future benefit payments, according to one estimate.[697] In comparison, MSCI emerging equities have returned 30% in dollar terms since 2006.[698]

A further trend accompanying this growth in FDI in developing countries over the last decade is the accumulation of foreign exchange reserves, particularly in Asian economies. Generally speaking, reserve assets have multiplied by a factor of 45 since the early 1970s.[699] Much of this growth has occurred since the 1990s. Between 1995 – 2005, world reserves more than tripled, with the rate of accumulation dramatically increasing between 2002 – 2005:

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[692] Mark Tran, 'Pension funds among biggest land investors in poor countries' , *The Guardian* (July 2011) <http://www.guardian.co.uk/global-development/2011/jul/01/pension-funds-big-investors-africa> [accessed March 2012]

[693] Sujata Rao, 'Global pension fund flows could swamp emerging markets' *Reuters* (13 May 2011) <http://uk.reuters.com/article/2011/05/13/uk-pension-emerging-idUKTRE74C5XD20110513> [accessed March 2012]

[694] Lindsay Whipp, 'World largest pension fund to dip into emerging markets', *Financial Times.com* (21 Aug 2011) <http://www.ft.com/cms/s/0/e7d1259c-c9ba-11e0-b88b-00144feabdc0.html> [accessed March 2012]

[695] Sujata Rao, 'Global pension fund flows could swamp emerging markets', *Reuters* (13 May 2011)

[696] Ibid

[697] Ibid

[698] Ibid

[699] International Relations Committee Task Force, 'The Accumulation Of Foreign Reserves', *European Central Bank Occasional Paper Series*, No. 43 (February 2006)<http://www.ecb.int/pub/pdf/scpops/ecbocp43.pdf> [accessed March 2012] p. 9

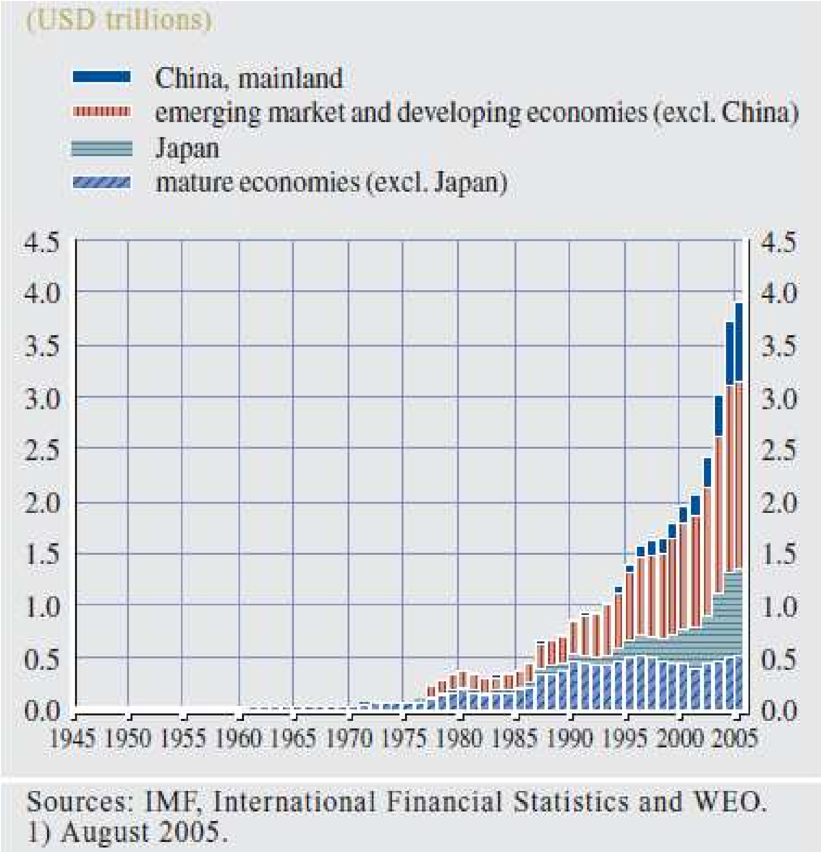

Figure 59: World foreign exchange reserves 1945 - 2005[700]

As the above chart shows, the accelerated rate of growth occurred mainly in emerging markets and developing economies, particularly in Asia and China. Oil-exporting nations, such as Russia, Algeria and Norway, also experienced significant growth in reserve holdings due to rising oil prices, especially since 2004.[701] In 2010, China topped the listings of the biggest international reserve holders with $2.3 trillion, followed by Japan, Russia, Taiwan (Province of China), India, South Korea, Hong Kong, Brazil, Singapore and Germany in the top ten.[702] Twenty years ago China had only US$18 billion, and ten years ago US$146 billion.[703] This is in direct contrast to the amount of deficit that many advanced economies find themselves in. The following map, based on CIA 2009 Factbook data, displays the stark discrepancy between countries and their relative total wealth, illustrating foreign currency reserves plus gold holdings minus total external debt:

[700] In ibid p. 10
[701] Ibid p. 11
[702] Tina Aridas and Alessandro Magno, 'International Reserves by Country – 2010 Ranking', *Global Finance* (2010) <http://www.gfmag.com/tools/global-database/economic-data/10212-international-reserves-by-country-2010-ranking.html#axzz1h4OXBkQh> [accessed March 2012]
[703] Ibid

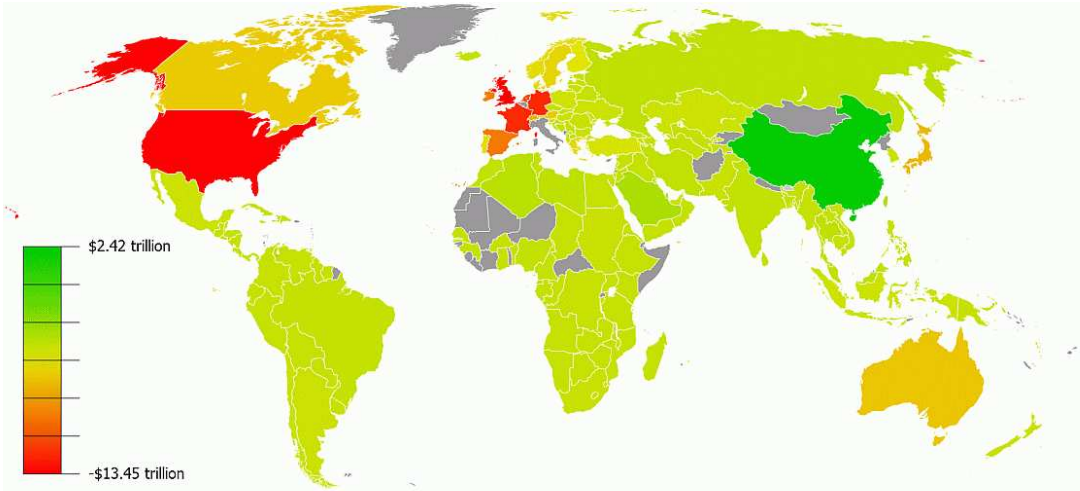

Figure 60: Global foreign currency reserves distribution[704]

The rapid rise of Sovereign Wealth Funds, mostly located in the Middle East and Asia, is another phenomenon dramatically altering the global financial landscape. The total value of assets managed by SWFs stands at $4.7 trillion.[705] Of the 10 largest SWFs by assets under management, six are located in Asia (four in China alone), three are in the Middle East, and one is in Europe.[706] The overall distribution of SWFs is shown below:

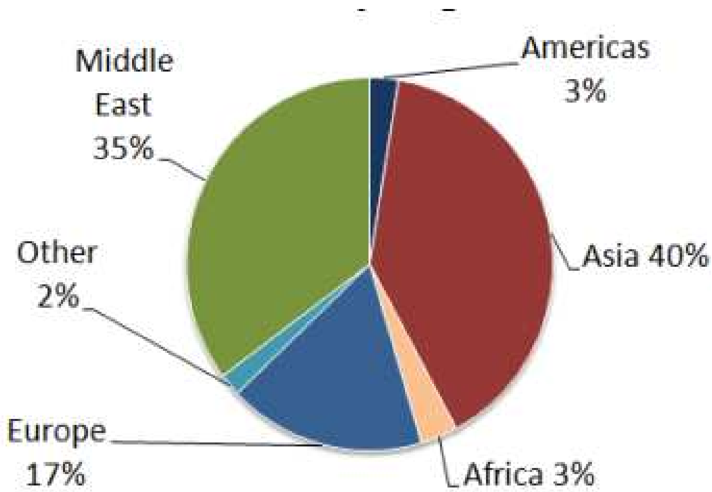

Figure 61: SWFs by Region[707]

A large proportion of these SWFs are created from the surpluses generated from resource exports; 58% are oil and gas related.[708] Investments made by SWFs include those in natural resources and infrastructure. In December 2011, Qatar Holding LLC was reported to be setting up a subsidiary called QH Indonesia to invest $1 billion in Indonesia's raw materials

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[704] Central Intelligence Agency, *The World Factbook* <https://www.cia.gov/library/publications/the-world-factbook/> [accessed March 2012]
[705] Sovereign Wealth Fund Institute, *What is a Sovereign Wealth Fund?* <http://www.swfinstitute.org/what-is-a-swf/> [accessed March 2012]
[706] Sovereign Wealth Fund Institute, *Sovereign Wealth Fund Rankings* (February 2012) <http://www.swfinstitute.org/fund-rankings/> [accessed March 2012]
[707] In ibid (Reproduced with permission.)
[708] Ibid

and natural resources.[709] Earlier in the year they also announced a $1 billion investment in European Goldfields, gaining access to physical gold reserves,[710] while Qatari Investment Authority, the 12th largest SWF in the world, invested more than $60 million in prime Australian sheep grazing land between 2010 – 2011 alone, with plans to grow this portfolio further.[711] In October 2011, UK Energy Minister stated that cash-rich SWFs from the Middle East were keen to invest in UK nuclear power stations.[712]

According to a World Bank article published in the April 2010 edition of its journal *Economic Premise*, maximising returns is the main objective for SWFs, but strategic considerations, such as ensuring future access to commodities, is probably also a key factor.[713] This can be seen in recent SWF activities, for example, the China National Offshore Oil Corporation has invested $2.3 billion in Nigerian oil and gas exploration.[714] The China Development Bank also launched the China-Africa Development Fund worth $5 billion to finance Chinese companies in Africa, including plans to explore energy development options.[715] The World Bank article reports that as a result, in February 2010, the oil industry in India called for the government to use parts of its $278 billion in foreign exchange reserves to create an SWF to "compete with China in the race to secure global energy assets".[716] However, unlike China, India is in deficit, and therefore the government is unlikely to fund this, according to Rashesh Shah, Chairman of Edelweiss Capital.[717]

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709 Sovereign Wealth Fund Institute, *Qatar Allocates Funds to Natural Resource Companies in Indonesia* (8 December 2011) <http://www.swfinstitute.org/swf-news/qatar-allocates-funds-to-natural-resource-companies-in-indonesia/> [accessed March 2012]

710 Garry White, 'Qatari wealth fund plans $10bn gold buying spree', *The Telegraph* (2 October 2011) <http://www.telegraph.co.uk/finance/personalfinance/investing/gold/8802793/Qatari-wealth-fund-plans-10bn-gold-buying-spree.html> [accessed March 2012]

711 Tom Cowie, 'Foreign ownership of Aussie land: the peril of selling the farm', *Crikey* (16 June 2011) <http://www.crikey.com.au/2011/06/16/foreign-ownership-of-aussie-land-the-peril-of-selling-the-farm/> [accessed March 2012]

712 Rowena Mason, 'Middle East sovereign wealth funds 'queue up' to invest in UK nuclear power stations', *The Telegraph* (5 October 2011) <http://www.telegraph.co.uk/finance/newsbysector/energy/8806965/Middle-East-sovereign-wealth-funds-queue-up-to-invest-in-UK-nuclear-power-stations.html> [accessed March 2012]

713 Stefano Curto, 'Sovereign Wealth Funds in the Next Decade', *Economic Premise* No. 8, World Bank (April 2010), <http://siteresources.worldbank.org/INTPREMNET/Resources/EP8.pdf> [accessed March 2012]

714 Ibid p. 4

715 Ibid

716 Ibid p. 2

717 Reena Zachariah, 'India may soon join sovereign fund club: fund to fuel natural resources acquisitions overseas', *The Economic Times* (8 September 2011) <http://articles.economictimes.indiatimes.com/2011-09-08/news/30130580_1_sovereign-wealth-sovereign-fund-natural-resources> [accessed March 2012]

5. Case studies

As was outlined in chapter 4 constraints on resources are seen across all major resources in all regions. However, it is difficult to understand how any resource constraint will impact the economy. In addition to complex interactions between a particular resource and economic growth there is also complex interactions between the resources. In chapters 6 and 7 we will attempt to build a simple systems model and explore qualitatively what these interactions may be and what impact they may have at the economy level.

Here we take two critical resources that are likely to have the largest impact in the short term – namely oil and water – and explore their interaction with particular sectors of the economy. Oil was chosen as a resource that is global in nature and water was chosen to illustrate a particular example of a local resource. Both exhibit resource constraints that can be considered short term.

5.1 Oil

Over the last 7 years oil prices have been over three times higher and almost three times more volatile (on average) than the previous 20 years.

- Average oil price per barrel 1985-2005[718]: \$22 ± 7
- Average oil price 2005-2012: \$78 ± 20

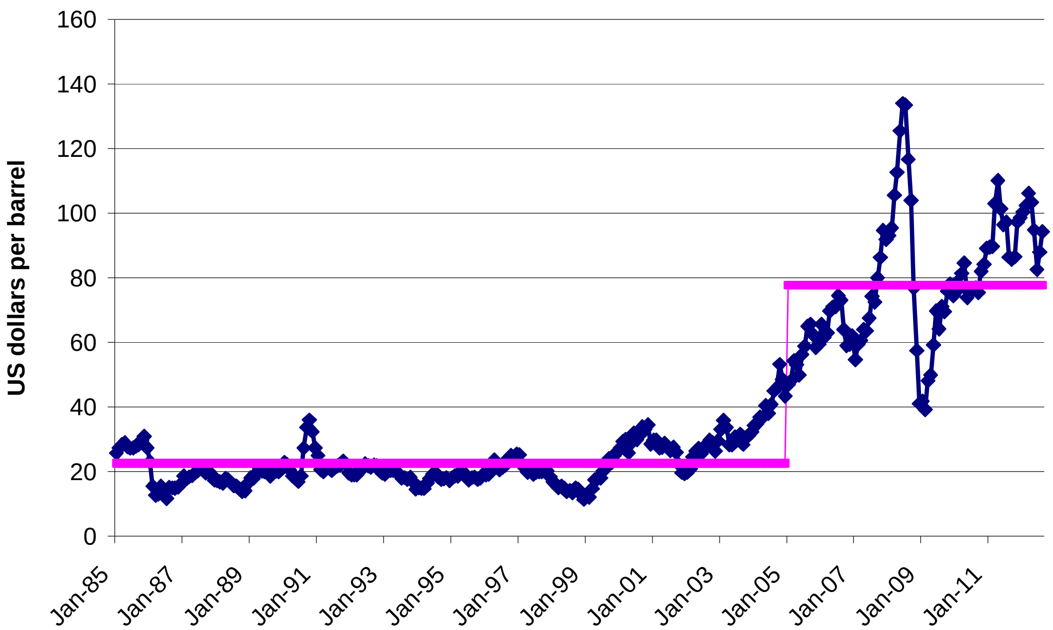

Figure 62. Price increase for oil showing step change in average and increased volatility.

With global demand for oil set to continue to rise for the foreseeable future it is likely that the pressures on reserves will grow. Increasingly these reserves are managed by national oil companies rather than privately held companies and therefore access to oil is likely to

[718] Derived from monthly barrel prices, Federal Reserve Bank of Louisiana, Dow Jones & Company http://research.stlouisfed.org/fred2/series/OILPRICE/downloaddata.

become increasingly politicised. 70% of the world's reserves are located in Saudi Arabia, Venezuela, Iran, Iraq, Kuwait, UAE, Russia, Libya and Kazakhstan.

With no control on oil consumption or production as supplies become increasingly strained markets are likely to respond with an increase in price. While the cost of exploration and extraction is rising (in particular for non-conventional sources) an increase in price will see much larger flows of capital into those organisations (countries) with oil reserves. On average, over the next three decades a significant flow of capital will be needed to access these reserves and trade balances will change dramatically as a result. As oil has been a critical resource in driving economic growth over the last century governments are, and will increasingly be, investing heavily in securing supply and developing partnerships or alternative technologies.

Increases in prices are likely to be very volatile and unpredictable depending on market feedbacks, short term political decisions and economic cycles. Short term drops in oil prices, driven by changes in demand, could lead to stranded assets and company bankruptcy for those overly exposed to unconventional oil. The potential for military conflict as oil supplies become constrained and short term price increases occur is ever present. In simplistic terms, at some stage, it will be much cheaper for a government to go to war with a country that has significant reserves than to purchase the oil they need on the open market (based on a pure cost-benefit analysis).

The prospect of increased difficulties in securing a stable oil supply together with increasingly volatile prices may increase the demand for alternative sources of fuels (whether this be renewable technologies, biofuels, liquefied fossil fuel from coal of gas) and, as a heavily politicised area, is likely to be a key focus of successive governments for many years to come.

5.1.1 Future price changes

As noted in Section 4.1 the average oil availability estimates are in the range 1,200-1,300 billion barrels left with the most optimistic estimates at 1,500 billion barrels. Current consumption (2010) is approximately 30 billion barrels per year which is projected to rise to 44 billion barrels by 2030. Assuming the best case scenario of reserves (1,500 billion barrels remaining[719]) at current consumption there is 50 years of oil left. With a linear growth in demand a simple calculation is possible to estimate the year oil reserves are exhausted (N=1 corresponds to 2010):

$$\text{Remaining barrels} = \frac{N(N-1)\times}{2}\text{Annual Growth} + \text{Base year consumption} \times N$$

Therefore, taking 1,500 remaining barrels, a baseline of 30 billion barrels per year in 2010 and annual growth of 0.7 billion barrels (consumption rising to 44 billion barrels per year by 2030) N is 35 years – oil runs out globally by 2045.

Taking personal transport as an example, we note that the average passenger car currently has a lifespan of 14 years (UK figures) [720] which means that just over two further generations of cars can be based on oil. If our current approach to personal transport is to continue as at

[719] Note that many oil companies use a lower estimate of reserves than this however to illustrate the example here we explore the 'at best' example.
[720] UK Commission for Integrated Transport 2001

present, a massive transformation of the car market, with the exponential penetration of new models and the associated technological advances and development of underlying infrastructure is required over the immediate short term. However, while there is currently some growth in this market, it is not at the scale noted here. The investment needed from both public and private sector to permit this fundamental change does not yet appear to be forthcoming.

However, an increasing price in oil is likely to curtail demand and drive innovation in alternatives. If we include a simple price feedback dynamic in the above simulation such that a quadrupling of oil price results in a global demand reduction of 10%[721] (if prices were at $400 per barrel compared to today's price of approximately $100 per barrel then the global economy would use 27 billion barrels per year as opposed to 30 billion barrels). We also assume price is inversely dependent on the amount of oil reserves left (so Price x Reserves is a constant). The output of this simulation is shown in the following figure.

It is noted that this model is very simplistic and oil price is not directly related to supply in this way. Steep increases and decreases in prices will be seen in the short term as various political and market responses encourage or discourage use or technological substitutions are developed. However, the underlying long term trend is ever increasing prices.

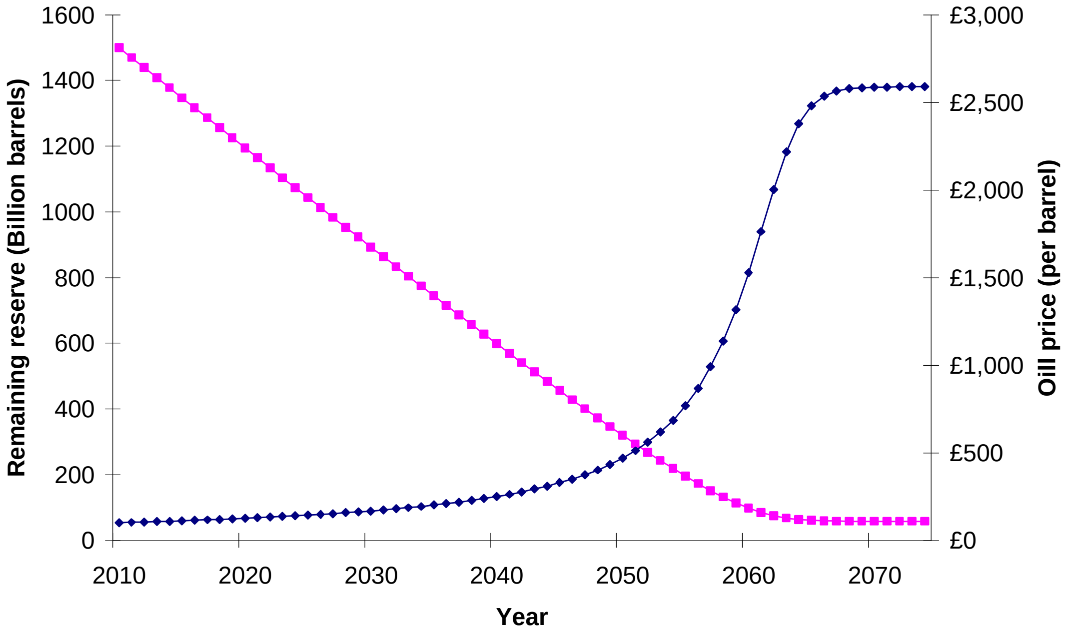

Figure 63: Oil reserves (pink) versus prices (blue) in simple simulation of demand

As can be seen within this simulation oil never runs out completely but shortly after 2065 oil consumption drops below 1 billion barrels per year and effectively stops being used. At this point oil is over $2,500 per barrel and there are just under 60 billion barrels left.

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[721] It is difficult to know exactly how an increase in oil price will impact demand however, during the 1970s oil crisis OPEC embargoed oil exports to the US and reduced production by 25% which resulted in a quadrupling of oil price in a very short period. Therefore, here we conservatively assume a quadrupling of price results in a 10% lower global demand. It is noted that these are very simplistic assumptions however they are only used to explore possible outcomes of a price feedback.

5.1.2 Limiting consumption: climate change?

All of the above presumes that changes in oil consumption will be driven by the market. However, an important constraint on oil consumption has now been agreed by governments. The climate change commitments (albeit voluntary) that governments have agreed to in various United Nation forum state that global greenhouse gas emissions should be limited to a level that will prevent a temperature rise of 2 degrees above pre-industrial levels.

Using probabilistic modelling the Potsdam Institute (as reported by the Carbon Tracker initiative[722]) have calculated that this translates to a global carbon budget of 565 $GtCO_2$ (Giga tonnes of carbon dioxide) between 2010 and 2050. It is also reported that, if burnt, the global oil reserves (using the higher projections for these) represent approximately 615 $GtCO_2$ (more than the total budget allowed for all sources). The total carbon stored in known fossil fuel reserves represents 2,795 $GtCO_2$.

Therefore, there are only a small number of solutions to this apparent issue:

1. Ignore the climate change limits
2. Allocate all 'allowed' emissions to oil
3. Capture all emissions from oil use
4. Restrict the amount of oil that can be burnt
5. All of the above (or at least a mixture)

Which of these (if any) are followed depends on political will. While long term targets and frameworks have already been agreed there is less evidence of the political reform that would drive real short term change.

5.1.3 Are energy companies appropriately valued?

The response by politicians and the market to this issue will have a significant impact on, for example, the valuations of infrastructure, stock markets and countries.

For example, if the climate change limits are ignored (or relaxed) then this in turn will have implications associated with increased impacts from climate change and short term valuations of renewable energy sectors. If all 'allowed' emissions are allocated to the burning of oil then coal, gas, agriculture, chemicals etc will have a very significant capital burden to bear associated with investments in carbon reductions or capture (and oil valuations are likely to soar).

Capturing all emissions from oil use may be possible if the use of oil is dramatically changed. There is no economically feasible way to capture oil burnt in vehicles and therefore this end use would need to stop as soon as possible to allow for other uses of oil to increase where capture is economically possible. This would have significant impacts on the valuation of car manufacturers who would need to invest heavily in alternative technologies rapidly.

Restricting the amount of oil that can be burnt would have major implications for the valuations of oil based assets. As reported by the Carbon Tracker Initiative[723] 20-30% of the market capitalisation of the stock exchanges in London, Sao Paulo, Moscow, Australia and

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[722] Carbon Tracker Initiative, 2011, *Unburnable Carbon – are the world's financial markets carrying a carbon bubble?,*
[723] ibid

Toronto is linked to fossil fuels. The report highlights a systemic risk on those markets connected with these assets (the companies listed on the markets cannot use all of their assets if global climate targets are to be met).

How restrictions are put in place will have a significant impact on the type of systemic risk these markets face. For example, if fossil fuel extraction is restricted (oil companies are given quotas for how much oil they are allowed to extract) then the likelihood is the value of an even more limited supply will be significantly higher. Therefore, these companies and assets may be undervalued (depending on whether those assets are 'allowed' to accrue this additional value or if this additional value is taken by governments through increased taxes on extraction). However, if restrictions are put on usage (demand rather than supply) and these prove to be effective then the value of limited supply is likely to reduce.

5.2 Water

Although 70% of the Earth's surface is covered in water, 97% of it is salt water and the remaining 3% (two thirds of which is frozen in ice caps and glaciers[724]) is freshwater suitable for human consumption and industrial activities. Water is a critical resource as it sustains most economic sectors and is used for agricultural, industrial, recreational and environmental purposes. Water scarcity can occur in all types of geographical areas even if rainfall or freshwater are plentiful; what determines the level of scarcity is an area's ability and capacity to conserve, maintain quality, use and distribute water to households, local businesses, industry and the environment.

5.2.1 The East of England

While the UK is reputed for its seemingly predictable wet weather, parts of the East of England suffer from severe levels of drought and the region is likely to face further levels of water stress due to increasing population and climate change over the next two decades. This could lead to water shortages, increased energy prices and further challenges for utilities operating in the region[725].

The East of England is a low lying area with diverse landscapes and rivers characterised by seasonal and annual variations of flow. Approximately 60% of abstracted freshwater comes from surface water and 40% from groundwater sources[726] which vary naturally in response to rainfall, temperature, soil moisture, soil type and geology. The region is comprised of Essex, Hertfordshire, Bedfordshire, Suffolk, Norfolk and Cambridgeshire and has a population of close to 5.8 million[727] with projected annual population growth rates of between 0.5% and 0.9%, higher than any other region in England. With its proximity to London, it has grown significantly since the 1950s with the commuter belt comprising the highest population densities. With increasing population densities, intensive agriculture and projected impacts from climate change the region's ability to provide water to its households and businesses is under a significant amount of pressure.

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[724] CERES (2009) Water scarcity and climate change: Growing Risks for Businesses and Investors. Authored by The Pacific Institute, February 2009

[725] Wilkins, M. (2012) *How water shortages in Eastern England could increase costs for UK-based utilities*. Credit Week Special Report: Water, 7 March 2012

[726] Environment Agency (2009) An environmental snapshot for the East of England. Environment Agency

[727] Office of National Statistics (2011) *Annual Mid-year Population Estimates, 2010*. Statistical Bulletin, Office for National Statistics

The East of England has an average annual rainfall of 600mm with a fairly even distribution across summer and winter periods[728]; this however represents less than two thirds of the UK's annual rainfall making the East of England the driest region of the UK. Annual rainfall in 2011 in the region in particular was very low with only 458.2mm representing 75% of the 1961-1990 and 1971-2000 averages[729] leading Anglian Water to apply for a drought permit to replenish its reservoirs[730].

Taking population densities into account, there is less water available per person in the East of England than some hotter countries such as Morocco and Egypt[731] and with increasing evidence of supply-demand issues as well as large numbers of people working and living in the region, water scarcity is an increasingly important issue.

At the individual level, an average of approximately 150 litres of water are used each day, the majority of which is used in the drainage system. Water in the East of England also suffers from pollution from point and diffuse sources (including industrial effluents, sewage treatment works and urban storm water drains), habitat degradation and low flows caused by drought and over-abstraction principally for agriculture. The quality of river water however has improved substantially since the 1990s with major investment in sewage treatment works[732].

5.2.2 Future water demand

The East of England Implementation Plan aims to reduce water consumption from 150 to 122 litres per day per person by 2030[733], representing an 18% reduction on current use for an average person with suggestions of more efficient water metering, fittings and the introduction of water saving technologies.

However over the same period climate change is predicted to have a significant impact on rainfall with large disparities between seasonal projections:

- 8% less summer rainfall and 8% more winter rainfall by 2030 for mid-estimate projections
- 15% less summer rainfall and 15% more winter rainfall by 2050 for mid-estimate projections and a 10% probability of 37% less summer rainfall and 30% more winter rainfall by 2050 for high emissions scenarios[734]

When considered alongside projected population increases in the region this change in available water leads to increased water scarcity. The main issues related to water scarcity in any region do not solely rely on water availability and do not always reflect the availability of water for domestic and industrial use, but are dependent on:

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[728] Sustainability East (2012) *A Summary of climate Change Risks for East of England*. Climate Action UK: Supporting action on climate change
[729] http://www.metoffice.gov.uk/climate/uk/2011/annual/averages.html
[730] http://www.anglianwater.co.uk/784F2E89480548778D5940523BD871C5.aspx
[731] Environment Agency (2008) *Water resources in England and Wales- current state and future pressures*. Environment Agency
[732] Environment Agency (2009) An environmental snapshot for the East of England. Environment Agency
[733] DEFRA (2008) *Future Water: The Government's water strategy for England*, Department for Environment Food and Rural Affairs
[734] Murphy *et al*. (2010) *UK Climate Projections Science Report: Climate change projections*. UK Climate Impacts Programme

- Changes in water availability (e.g. changes in seasonal rainfall)
- Availability of water treatment
- Catchment characteristics (e.g. soil quality)
- Changes in level of deployable output and extraction rates
- Changes in demand depending on season

These changes increase the likelihood of drought and flooding events[735] as well as change the components of the freshwater system which are '*expected to affect food availability, stability, access and utilisation*'[736]. Prolonged spells of dry weather (particularly in the summer) and over-abstraction for public water supply and crop irrigation will reduce water volumes in rivers resulting in higher levels of pollutants and increased risks of flooding due to extreme events of heavier downpours.

5.2.3 Impact on debt and finance

As reported by Standard & Poors[737] the impact of changes in water availability and the increased likelihood of extreme weather events, as well as coastal flooding, could have an impact on the major utilities that operate in the East of England. For example, Anglian Water have reported that they have 2 water treatment works and 58 wastewater treatment works in coastal flood plains less than 40cm above sea level – all projected to be underwater by 2080 without additional investment in sea defences. Anglian Water have a 5 year, £1 billion investment strategy for flood defences.

In addition the likely impact of scarce water on energy utilities is significant. Analysis by Trucost (as reported by Standard & Poors) shows that Sizewell (owned by EDF Energy) could incur water scarcity costs of £2 million each year by 2025 based on 2010 consumption patterns. In addition Sizewell is located on the coast and could be at increased risk of storm surges if increases in sea levels occur at a faster rate than predicted in climate models (most commentators say that projections for sea level rise are conservative).

Water scarcity costs for Tilbury B (owned by RWE NPower) could total £51 million a year. Tilbury B is due to switch from coal to biomass between 2012 and 2015 which could increase its water requirements. This increase in water scarcity cost, if internalised and passed onto consumers could lead to a 6% increase in electricity prices for the region (Trucost modelling was extended to all major power plants in the region). Therefore, while no immediate risk is seen from changes in water availability, the likely medium term changes in rainfall patterns resulting in both drought (water scarcity) and extreme rainfall (flooding) events require major utilities to invest significantly in measures to better manage water. This investment invariably results in lower returns to investors in those utilities or higher costs to consumers of electricity or water which in turn results in higher operational costs for households (lower disposable income) and/or industry in the region. Both would have implications for actuaries.

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[735] Intergovernmental Panel on Climate Change (2007) Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[736] Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., (2008) *Climate Change and Water*. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp. page 3.

[737] Wilkins, M. (2012) *How water shortages in Eastern England could increase costs for UK-based utilities*. Credit Week Special Report: Water, 7 March 2012

6. Scenarios for the future

The implications of the resource constraints are not straightforward. How we respond as a society, economy and political system is critical in understanding whether the availability of a certain resource or the impact of climate change or land degradation will be significant or not.

In chapter 4 we outlined the evidence for constraints across a number of critical resources including oil, coal, natural gas, land and soil, water, commodities (metals and food), population and capital. The key conclusion for every one of these resources is that while some are scarcer than others each one is seeing a general trend towards price increases driven by a variety of factors including lower ore quality, more complex geographies involved in the extraction (for example deep ocean drilling), over extraction or use (especially in water and soil fertility) and geo-political issues.

It could be argued that if only one of these resources had a potential economic impact then the market could respond appropriately, if not perfectly, through pricing and shifts in technology and services. However, the multiple overlapping resource constraints, coupled with climate change, may produce a systemic risk that is more difficult to respond to. For example, a shift away from oil could see increased use of gas or renewables which in turn are more expensive due to the increasing costs of water and rare earth metals. Chapter 5 explored some of the issues associated with two resource constraints in isolation. In this chapter we will attempt to bring together all resource constraints.

Given the global nature of the problem, and the lack of a clear and consistent database (and model for how resources impact on the economy and finance), we need to adopt a different approach to explore whether the implications of resource constraints are significant enough to warrant further attention and research by the actuarial profession.

The use of scenario techniques (see Mietzner & Reger 2005[738]) has been very effective in exploring these types of issues in the past. For example, Shell used scenario planning to predict some of the possible implications of a future oil shock prior to the events in the 1970s. Mietzner & Reger argue that scenarios approaches:

- open up the mind to hitherto unimaginable possibilities and challenge long-held internal beliefs of an organisation
- are an appropriate way to recognise 'weak signals', technological discontinuities or disruptive events and include them into long-range planning.

In this chapter, through the use of scenarios techniques, a range of options of how society may adapt, or not, to the constrained (more expensive) resources over time is explored. These scenarios are then used to set up the background for the subsequent case study of the possible implication for an actuarial case study in the following chapter.

6.1 Scope for the scenarios

The global economic system has increasingly become focussed on finance. However, it evolved as a way of managing, in an as efficient manner as possible, the flows of resources required to deliver the services we want (see Figure 65).

[738] Mietzner & Reger, 2005, *Advantages and disadvantages of scenarios approaches to strategic foresight,* Int. J. Technology Intelligence & Planning, Vol 1, No. 2, p220-239

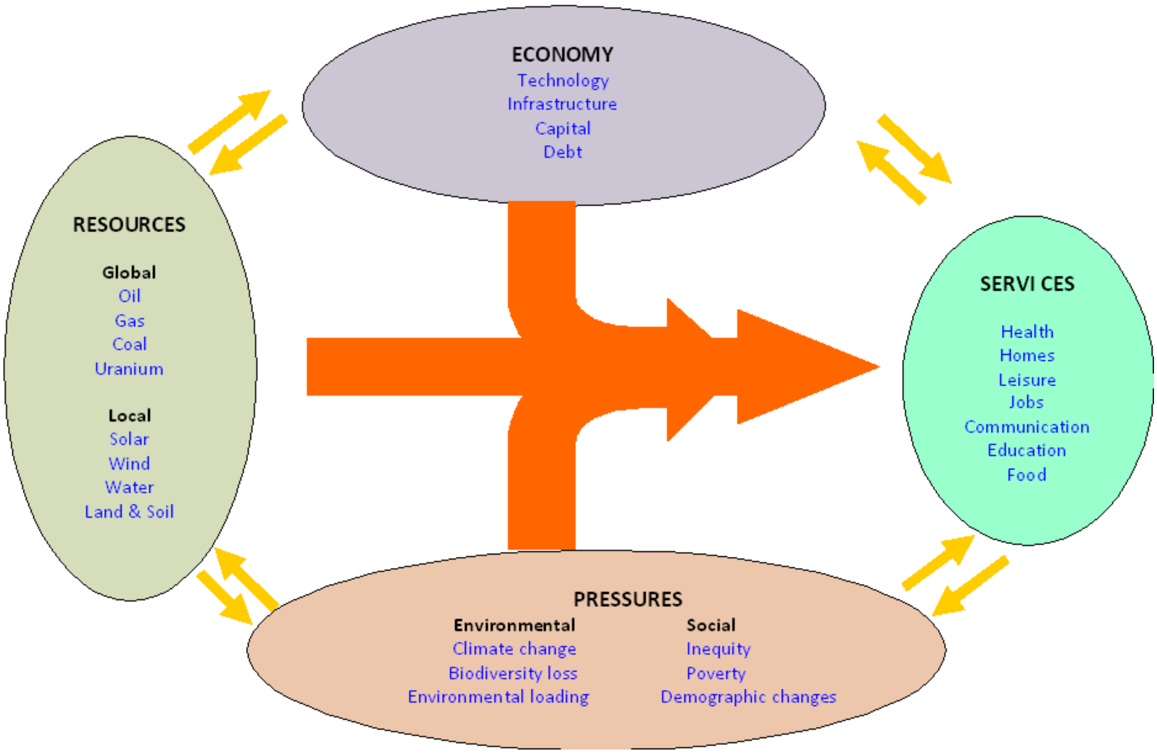

Figure 64. Global flow of resources to services (the basis of the systems view).

To understand the likely impacts of resource constraints we need a method that allows us to explore some of the interactions within the system. We need to look at underlying trends, short term 'shocks'[739] and start to develop an understanding of at what level of impact a short term 'shock' event would become a permanent shift away from the underlying trend.

Within the scenarios we wish to explore where risks appear and attempt to articulate some of the areas that may have a significant impact on the overall shape and size of the economy. For example, how will the economy be impacted by changes to resource pricing, what impacts will this have on society and what does the geographic mix of impacts look like.

Two time horizons will be explored – 2030 and 2080. 2030 is chosen as just beyond a typical investment horizon (out to 10 years) to explore the near term impacts of resource constraints. 2080 is chosen as a long term investment horizon corresponding to just beyond the expected retirement of a new joiner in a pension fund.

[739] Here we define a short term shock as an event, whether cyclical or one-off (for example, recession or hurricane), from which the economy recovers and returns to the underlying trend.

6.1.1 Modelling financial implications

Investment funds have different exposures to resource constraints. Pension funds, insurance funds and public sector funds all have different investment mandates (see table below)[740]. The geographic spread of investments also needs to be taken into account with, for example, UK fund equity allocations (2010) in UK (42.6% - down from 59.2% in 2006), EU (19.9%), North America (15.1%), Pacific (ex Japan) (7.9%), Japan (4.3%), Emerging markets (9.7% - from 1.8% in 2006 although the public sector is particularly exposed – 31.2%) and other (1.1%) and bond allocations (2010) in UK Government (21.3%), UK Corporate (37.4%), UK Index Linked (15.5%), other UK (1.8%) and overseas (24%). Chapter 7 will explore in more detail how to further explore the finance impacts of resource constraints.

However, while asset allocation may expose some funds more than others to particular short term risks (or opportunities) associated with resource constraints the Universal owner hypothesis states that large institutional investors usually have diversified and long term portfolios that expose them to the overall risk within an economy – if the economy starts to contract then the value of the institutional investor will inevitably contract as well. Therefore, any large investor (and any small investor following the same asset allocation criteria as large investors or with passive investment mandates) are exposed to all correlated and systemic risks in the economy. Therefore, the scenarios developed in this chapter will focus on the overall risk to the economy rather than particular asset classes. Further work would be needed to explore asset class risk.

There are multiple overlapping risks to the economy and finance within the global system. While exploring the scenarios the main risks we will consider are as follows:

- *Policy risk*
- *Technology risk*
- *Physical risk*
- *Security risk*

6.1.2 Policy risk

The largest risk to capital and finance is the risk associated with changes to policies that could undermine or enhance specific sectors and technologies. This is particularly true when considering climate change solutions as government's are developing new policies within this space.

6.1.3 Technology risk

One possible outcome for the global economy is that a new technological development does indeed provide access to clean, low cost, resource light energy at scale (it is assumed here that a key driver for economic growth remains access to low cost energy). For example, cold fusion, a revolution in thin film technology for solar energy capture or a very significant increase in the output per land mass of bio-energy linked with carbon capture technology. There could also be a new technological revolution based on a completely different way of working and driving economic growth (the rise of the internet for example has radically altered global economies). However, conventional economic models are not very good at capturing real underlying market drivers in times of uncertainty. For example, Richard

[740] Asset Management in the UK 2010-2011, The IMA Annual Survey, Investment Management Association (2011)

Werner[741] explores the limitations of neoclassic economic models by looking at the Japanese economy.

Predicting these types of positive technological shocks is very difficult. However looking at technology development cycles (from research, through development, to testing and deployment) it is more possible to map where these may have a significant enough impact on resource limits to affect scenarios. Some of the 'known' technologies currently under research and development will be included in the scenarios to explore the potential for them to have an impact.

6.1.4 Physical risk

In addition to direct physical risks from climate change (such as flooding, drought, heatwave, hurricanes) which are explored within the scenarios and extensively in other reports there is a potentially significant indirect risk from the loos, or disruption to, ecosystem services.

There are a number of regulating ecosystems which are vital to the economy and society (such as the fertility of soils, water supply, carbon sequestration, fish). However, the long term implication of loss of 'general' biodiversity is unclear and therefore more difficult to include in these scenarios. Indeed studies have shown that we are already in a global mass extinction event with extinction rates now estimated at between 100 and 10,000 times higher than fossil record rates[742]. The 'business as usual' economy has been shown to 'not care' about this.

For the scenarios presented here we will not add in a 'moral' judgement around the value of biodiversity in general and therefore only systems that are demonstrably 'useful' to society in the medium term will be included.[743]

6.1.5 Security risk

Economic growth over the past century has dramatically reduced global poverty (a large part of this is down to the economic development of China). However, equity (global and local) is poorly defined and is increasingly being examined – is it right for the highest earner in an organisation to be paid 200 times more than the lowest earner? This issue does not lead to a simple physical limit but is attached to a moral question around the purpose of the economy.

For the purpose of these scenarios we will explore indirect equity questions where they could have a large impact on resource use including a reduction in global poverty through a 'race to the top' (an overall increase in consumption). In addition if resources do become scarcer and more expensive over time then equity becomes more of an issue as access to these resources is more likely to become an increasingly important political question.

Increasing focus is being given to global threats such as food price instability[744] and climate change by defence agencies (such as the CIA or the Ministry of Defence in the UK). This is not only to protect the citizens of the country but also to protect the stability of the country. For

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[741] The new paradigm in macroeconomics", Richard Werner, 2005
[742] Mace et al, 2005, *Chapter 4: Biodiversity, Ecosystems & human-wellbeing, current state and trends,* Millennium Ecosystem Assessment.
[743] The authors wish to note that this is not a reflection on their own views or the views of the actuarial profession – rather an extrapolation of where the current system is.
[744] R Arezki & M Bruckner, IMF Working Paper, 2011

example, food price increases can lead to increased political instability and therefore increased food prices can be correlated to increased military spend in certain circumstances. The 'Arab Spring' has been linked by some commentators to increased food prices alongside other social issues.

How economies respond to acute resource constraints is important to the global economic system. Countries respond very differently to similar threats. For example, Friedrichs has explored country response to increased energy prices[745] and proposed that Japan embarked on 'predatory militarism' (1940s), North Korea on 'totalitarian entrenchment' (1990s) and Cuba on 'socioeconomic adaptation' (1960s). The scenarios will try to explore some of the tipping points in the economy that would increase the likelihood of a security response by a government – however, it will not attempt to predict the style of this response.

6.2 Constructing the scenarios

To understand how resource constraints may impact economic development in an uncertain future we need to explore how these issues drive global change. There are two key agents in enabling the flow of resources around the world and offer some form of 'management' to this flow - governments and markets (such as finance and commodity markets). Therefore, we will build scenarios based on their sensitivity to future resources constraints.

High sensitivity implies long term planning drives decision making and resource stocks (how much of a particular resource is left) are a key element in day-to-day policy development or market pricing. Low sensitivity implies short term impacts drive decision making and prices reflect current flows and production of resources rather than long term stocks. Political decisions are driven mainly by resource availability within political cycles (2-5 years).

The sectors (government and markets) are mapped onto two axes with a scale from low to high sensitivity for each (see below). Each quadrant of this plot then corresponds to a different scenario that we will explore further.

Not one of these scenarios is 'correct' and they are set up to explore the extremes of decision making. They are artificially created and constrained along the axes as outlined (we do not allow a future scenario to move between quadrants). The way the world actually responds to resource constraints is highly unlikely to follow any one of these scenarios as it won't be constrained to stay in one quadrant. For example, the world could start along a business-as-usual trajectory, then agree a policy framework to manage climate change, followed by oil price increases, each driving different changes.

It is very often the case that real political or economic paradigm shifts only happen following significant conflict (for example, the emergence of global governance frameworks following World War II). As resource constraints may trigger conflict it could be argued that the most likely scenario the world will follow is conflict driven change. The scenarios do not explore these paradigm shifts in political governance.

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[745] Friedrichs, *'How different parts of the world would react to a peak oil scenario'* Energy Policy, vol 38(8), 2010

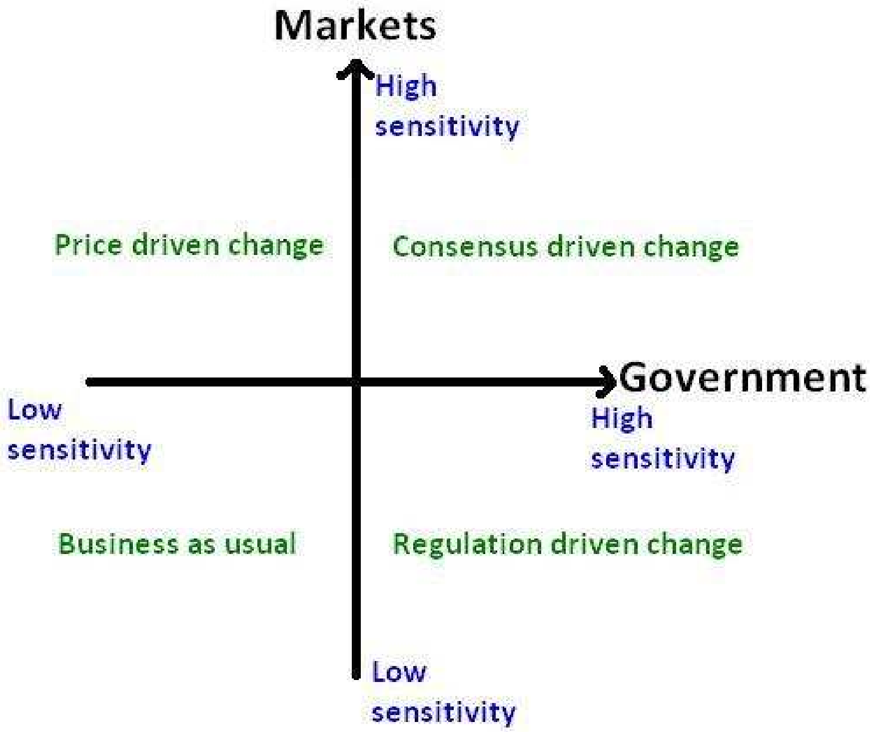

Figure 65: Scenario map showing sensitivity of the governments and financial markets. Each quadrant corresponds to one of the four scenarios.

The four scenarios outlined above are expanded below:

Business as usual
Governments and financial markets have a low sensitivity to resource limitations. Prices for resources are set based on short term availability (supply and demand) and government regulation focuses on managing the flows of these resources rather than their stocks. Decision making for both the finance sector and government does not take into account limits to resources.

Price driven change
Governments have a low sensitivity to resource limitations while markets have a long term outlook of the stock availability of resources. Price signals within the market are set based on the long term availability of resources. However, no regulation is put in place to manage the availability of resources.

Regulation driven change
Governments operate on a long term basis and regulate the stock of resources rather than the flows. The market responds to regulatory change in a short term way. The feedback from market change to policy development is not always effective.

Consensus driven change
Governments and the market operate on a long term basis by pricing and regulating the stock of resources rather than the flows.

6.3. Running the scenarios

The following summarises the outcomes of each of the four scenarios:

- Business as usual
- Price driven change
- Regulation driven change
- Consensus driven change

Each scenario is set towards the end of the century and articulated in a way that looks back over the changes seen.

6.3.1 Business as usual

Governments and financial markets had a low sensitivity to resource limitations. Prices for resources were set based on short term availability (supply and demand) and government regulation focused on managing the flows of these resources rather than their stocks. Decision making for both the finance sector and government were based on no limits to resources.

Price signals were delayed. For example, increases in oil prices came long after a peak in production and therefore did not drive a sufficient increase in investment into alternative sources of energy in time to allow a substitution of technologies. When investments were made into alternatives markets found energy prices were too high resulting in capital requirements and often local resources, in particular water, meant uncertain supply chains causing regular shut downs of industrial output. Government regulation failed to adequately protect resource stocks. Resource prices continued to be volatile.

When resource limits were approached, or short term political issues impacted on the availability of a scarce resource (for example, embargos on oil exports by some countries were put in place at different times throughout the century), there were abrupt and discontinuous changes to resource availability and price.

Economic growth

There was an immediate boost to the US economy with increased use of fracking (hydraulic fracturing) for natural gas[746] leading to lower energy prices. Overall global economic growth meant limited oil supplies became more of an immediate threat and another doubling of prices[747] was seen over a very short period. Most other countries were more exposed to this price increase than the US and therefore increased investment into alternative sources.

By the middle of the century increased domestic water competition[748] in the US resulted in the closure of several fracking sites leading the US to be suddenly exposed to international gas and energy markets again. This caused a significant shock to the US economy lowering industrial output sharply. The US had not diversified its industrial capacity or energy infrastructure and was therefore more exposed than other countries to high energy prices.

China continued to grow and expand its production capacity while becoming a much more resource efficient economy. However, despite this the use of fossil fuels, in particular coal,

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[746] http://www.bloomberg.com/news/2012-09-04/ohio-s-gas-fracking-boom-seen-aiding-obama-in-swing-state.html

[747] See Chapter 5

[748] http://www.scientificamerican.com/article.cfm?id=fracking-evolving-truth-natural-gas

grew rapidly, which had a significant impact on the health of the workforce in and around industrial centres[749]. This lowered the industrial productivity per head resulting in higher costs and lower international competitiveness. The Chinese economy stagnated as international demand vanished due to stagnation in the US and domestic demand being undermined by significant health and environmental impacts.

Despite some increase in productivity in agriculture in Europe (in particular in Eastern Europe[750]), climate change impacts were felt and another long term drought in the US[751], combined with catastrophic flooding in Asia[752], resulted in acute shortages of food and a large increase in global food prices. The role of agriculture insurance increased. This food crisis, combined with high energy prices, led to another great depression in the US.

The world continued to see an increase in real commodity prices[753], driven predominantly by the increasing reliance on lower extracted ore quality, and a significant increase in the cost of bringing new oil wells online as exploration moved to the Arctic (which became ice free) and further deep ocean sources. Therefore, an increasing percentage of GDP and industrial activity was focussed on extraction of resources. Part of the GDP rise during this period did not translate into a commensurate level of increase in throughput (it was a rise in 'unproductive' GDP – the investment needed in more expensive extraction infrastructure rather than increasing productivity output).

During the long term decline and depression seen in the US economy many large corporations filed for bankruptcy. The increasingly limited supply of resources all but stops being traded internationally. Despite increased resource efficiency the increasing dependence of Europe on external sources of energy caused currency instability.

Social cohesion and security

In the short term there was a small decline in mortality rates in Europe because of a reduction in cold winter deaths due to climate change[754]. Ageing populations, combined with a reticence by governments to increase retirement ages in line with ageing trends, in most developed countries reduced GDP growth rates[755]. Urbanisation continued globally with lower birth rates seen in urban areas which somewhat alleviated the problem of global population growth that would otherwise have been seen.

There were no changes to consumption patterns in developed countries and developing countries increased their domestic consumption to create more internal drivers for GDP growth. In the short term the average person on the world was older, wealthier and healthier. However, inequity within all countries had worsened[756].

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[749] Wu, Wang, Streets, Hao, Chan & Jiang, *Environ. Sci. Technol.*, 2006, *40* (17), pp 5312–5318

[750] UK Government Office for Science Foresight Project on Global Food and Farming Futures, *Regional case study: R7 Agricultural production potentials in Eastern Europe up to 2050 in the context of climate change*, 2010

[751] S&P CreditWeek Report, *Dry as a Bone: Corporate Credit Impact of the US Drought,* 5 Sept 2012

[752] http://www.bloomberg.com/news/2011-10-23/flooding-in-southeast-asia-may-cause-food-shortages-un-says.html

[753] 147% increase in real commodity prices since the turn of the century (Mckinsey, 2012 – Resource Revolution: meeting the world's energy, materials, food and water needs, Mckinsey Global Institute & McKinsey Sustainability & Resource productivity practice)

[754] http://climatex.org/articles/climate-change-info/climate-change-and-health-europe/

[755] R Arnott, D Chaves, Financial analysts journal, vol 68, issue 1, p23

[756] http://www.oecd.org/els/socialpoliciesanddata/dividedwestandwhyinequalitykeepsrising.htm

Food and energy price volatility had resulted in a reclassification of energy poor as most countries would have been classified as energy poor using previous definitions. The average household now spent twice as much on energy and the availability of certain types of food was sporadic. The depression in the US and its global impact had a significant negative pressure on measures of wellbeing.

Towards the end of the century climate change impacts were significantly impacting mortality rates everywhere. In Europe and the US increased heat deaths in the summer resulted in a significant increase to the death rate[757]. Extreme weather events were much more common and insurance targeted at mental health (in particular depression) became increasingly difficult to financially sustain[758].

Coastal flooding caused the relocation of populations and infrastructure for several large cities on every continent although the majority of this movement was within countries. Property insurance was no longer available in coastal areas or regions that were impacted by regular extreme weather events resulting in a collapse in valuations.

A significant proportion of Africa could no longer support its own population by mid century resulting in sustained and large scale famine and mass migration[759]. However, no country could absorb the level of immigration or provide the support needed at scale and therefore increased militarisation of borders was seen. China became increasingly nervous about protecting its borders from millions of immigrants. Internal civil unrest within China increased with regions worst affected by resource shortages, in particular water, causing significant internal migration.

The increase in energy and food price volatility, coupled with an increase in income and wealth inequity, resulted in a new wave of civil unrest dubbed the 'Asian Autumn' (following a reference to the Arab Spring seen in the early 2010s). Asia was particularly badly hit by food shortages following on from severe floods during the summers. The US and EU had been hit by drought and therefore had no capacity to increase food exports and indeed banned exports of certain types of food.

With some parts of the world destabilised the availability of certain resources became even more restricted as supply chains were disrupted causing issues globally. There was an increased spend on military budgets by developed countries[760]. China became more interventionist as neighbouring countries threatened to destabilise and key resources that it required were threatened.

The first water wars[761] broke out by mid-century as countries constructed dams in large rivers stopping them from flowing across borders to other countries.

By mid-century democratic governments found that policies which had been implemented to ensure resources prices were artificially lower for their citizens became increasingly

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[757] http://www.nrdc.org/globalwarming/killer-heat/

[758] Fritze, Blashki, Burke & Wiseman, 2008, *Hope, despair and transformation: climate change and the promotion of mental health and wellbeing,* Int. J. Mental Health Systems, http://www.ijmhs.com/content/2/1/13

[759] http://allafrica.com/stories/201008090190.html

[760] P Smith, *Climate Change, Mass Migration and the Military Response,* Foreign Policy Research Institute, Elsevier Ltd, 2007

[761] http://www.reuters.com/article/2012/07/23/us-water-southasia-idUSBRE86M0C820120723

unaffordable leading to short term and rapid price increases. Mass protests were a common occurance and some countries broke down into regional tiers of government.

Towards the end of the century there were many more countries in the world with far fewer people. Some remained democratic in nature while others operated more like corporations with increased power for the civil service with politicians acting more like an advisory board. Some countries fell into autocractic rule.

	2030	2080
Corporates	Gains in the US through gas fracking make way for increased volatility and a doubling in global prices around 2030 as fracking becomes unviable due to water shortages. Droughts and floods result in food crop failures globally. Energy prices and food prices are high and volatile. Agricultural insurance products are popular.	The global economy did not respond in time to limited supplies and price signals were too slow. Innovation did not happen quickly enough so globally markets in energy, transport and manufacturing collapsed. There are no listed equities anymore with local enterprise responding to particular local needs.
Governments	North American government borrowing continued and over a short period was seen as low credit risk although on a negative watch. Asia was mixed as some countries fall into civil war and so increased credit risk is seen.	Governments can no longer raise debt capital as no growth exists on an economy wide scale in any country. Asia is in the grips of large and prolonged wars. The US economy suffered long term decline resulting in mass civil unrest and prolonged hardship. Following an early shock the new European Union is rebuilding a regional economic block although parts of southern Europe are no longer habitable during summer months due to climate change.
Society	No immediate impact on wellbeing is seen apart from certain regions where severe drought caused localised fires resulting in massive loss to property and health. Insurance losses increase and certain areas become completely uninsurable.	Property prices have collapsed in developed countries as economies declined. However, there is a severe shortage of homes in particular areas hit by coastal flooding. Regular summer fires make insurance unaffordable in West Coast US.

Table describing key outcomes.

Long term projection

Pessimistic predictions: *Long term global economic decline (based on energy availability) and local economic decline (based on food and water availability)*

Optimistic predictions: *Slightly delayed long term global economic decline and some areas stabilise.*

6.3.2 Price driven change

Governments had a low sensitivity to resource limitations while markets had a long term outlook of the stock availability of resources. Price signals within the market were set based on the long term availability of resources and therefore drove substitution towards more abundant resources. However, new prices on other resources (such as ecosystems or a global carbon price) as a policy instrument were not introduced. No regulation was put in place to manage the availability of resources for society as a whole.

Innovation within business was driven by investment into alternative technologies. The market priced resources according to their long term availability and only those that could afford to pay gained access to those limited resources. Energy prices and resource prices continued to rise steadily until new technologies came online. Technological or process solutions were sought for all resource limitations.

There was an increasingly inequitable distribution of resources (both globally and within countries). For example, the price of fossil fuel rose which led to wealthier countries, organisations and individuals having a disproportionate share which in turn led to wealth creation for them further exacerbating the inequality.

Economic growth

With commodity prices, and in particular oil prices, rising sharply due to increased demand from all economies a significant investment into new oil fields and extractive industries was seen (as opposed to investments into alternative technologies). This investment caused 'peaks' of oversupply as new oil fields and other sources of resources became available. Therefore, commodity prices remained very volatile as large increases in prices were followed by short term price collapses. However, the underlying long term trend in prices was upward[762].

Industrial groups lobbied for the rejection of new, or the relaxation of existing, environmental legislation[763,764] to ensure lower grade ores and mines/wells could continue to be extracted or new sources in difficult to access areas could be made economical. In particular new coal mines and fracking wells expanded in China and the US resulting in higher localised environmental impacts including sulphur emissions and groundwater sources being contaminated and an increased occurrence of man-made seismic events. Power stations were either kept open or new ones built.

[762] http://www.mpettis.com/2012/09/16/by-2015-hard-commodity-prices-will-have-collapsed/
[763] http://www.natlawreview.com/article/lobbying-against-clean-air-environmental-group-condemns-eight-utility-companies-spen
[764] http://www.nytimes.com/2012/05/24/science/earth/shell-arctic-ocean-drilling-stands-to-open-new-oil-frontier.html?pagewanted=all&_r=0

Prices for food continued to rise as phosphates and fossil fuel derived fertilisers became more expensive and more instances of extreme weather lowered the productivity of land[765]. Land investments continued to increase and China, the Middle East and large private enterprises owned significant parts of Africa and Asia[766]. By mid century the oil market collapsed. However, with traditionally low or non existent debt the Middle East became a significant exporter of food globally from its large farms across Asia and Africa. In Latin America arable land took precedence over protected areas and, coupled with a massive wildfire[767] caused by record temperatures and drought, a large proportion of the Amazon rainforest was turned permanently into savannah. This collapsed the new financial market in ecosystem services and carbon sequestration insurance.

By mid century fossil fuel prices were high enough to drive new innovations in exploration. For example, with climate change now causing permafrost and deep ocean gas hydrates to thaw[768] in the Arctic new methane capture plants were deployed[769]. Carbon dioxide emissions sped up and extreme weather events were common place everywhere. Sea levels by the end of the century were 2m higher than at the start of the century in some regions[770]. This increased sea level rise had resulted in a significant investment in flood defences in high asset value cities such as New York and London while other cities had become uninhabitable[771]. Coastal flood insurance and weather insurance was no longer a financially viable market.

Global GDP continued to rise until the middle of the century. However, the majority of the increase was due to investments in increased extraction costs of resources[772] and in protection of infrastructure from extreme weather events (a shift from consumption GDP growth to investment GDP growth). The Middle East and China had very large investment holdings as did a handful of large commodity financial houses in Europe and the US. These private enterprises, alongside China, were managing the food and fuel flows for the US and Europe and little power remained in the hands of elected politicians.

Social cohesion and security

Urbanisation continued[773] throughout the first part of the century and accelerated towards the middle of the century. Increasing percentages of rural lands were bought and managed by China, Middle East and large private enterprise. As scarce resources became more expensive they started to have a larger impact on urban populations. This included indirect impacts such as lowering the availability of investment capital for infrastructure to support the urban 'poor' including access to basic education. This led to birth rates rising again[774] leading to a renewed growth in global population over the short term.

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[765] http://www.ft.com/indepth/rising-food-prices
[766] http://www.bbc.co.uk/news/world-18039528
[767] http://www.amazonrainforestnews.com/2012/04/amazon-rainforest-in-flames.html
[768] Ruppel, C.D. (2011) *Methane Hydrates and Contemporary Climate Change*. Nature Education Knowledge 2(12):12
[769] http://cosmiclog.nbcnews.com/_news/2009/08/20/4351090-a-new-energy-frontier?lite
[770] Willis, JK & Church, JA (2012) *Regional sea-level projection,* Science 336 (6081) pp 550-551
[771] http://www.oecd-ilibrary.org/content/workingpaper/011766488208
[772] Guildford, CG, Hall, CAS, O'Connor, P & Cleveland CJ, (2011) *A new long term assessment of energy return on investment (EROI) for US oil and gas discovery and production,* Sustainability, 3, 1866-1887
[773] http://www.icup.org.uk/reports%5CICUP601.pdf
[774] http://www.cdc.gov/nchs/pressroom/97facts/edu2birt.htm

By the middle of the century all major cities had large ghettos and climate change made water availability in these cities limited resulting in an increase in hygiene-linked diseases[775]. The poorer regions of Africa and Asia could not get access to key resources including food as global prices continued to rise. Some countries that had previously been classified as emerging slipped back into 'developing' status. Famine was common place in the majority of countries in the world and the global population halved.

Industrial accidents had a more immediate impact on communities as new wells and mines were located closer to population sites in particular in the US. Two concurrent years of hurricanes causing tidal surges in downtown New York resulted in severe economic loss and rationing which then resulted in rioting. A lot of military spending was now coming from the private sector who had invested in protecting resources and therefore relief efforts were harder to centrally coordinate. The lack of investment available from federal government in the US caused its citizens to join the 'brown' revolution. Towards the end of the century the US was on the brink of civil war.

	2030	2080
Corporates	Increases in prices for all commodities and fossil fuel drove investment into extraction and drilling in more inaccessible locations. Land was increasingly owned by China, Middle East and a handful of large private enterprises.	The global economy was effectively managed by a small number of private enterprises, China and the Middle East. The majority of investment was in extractive industries with liquification of low grade coal now taking the place of oil. Gas hydrates and permafrost methane capture were new innovations for the energy industry. Climate change had made large portions of the world un-insurable.
Governments	Governments were unable to resist pressures to relax environmental legislation and do not invest public money in adaptation measures at any significant scale.	Population collapse from starvation caused several countries to cease to exist, go to war or become completely reliant on foreign aid. National boundaries were increasingly irrelevant.
Society	Some impacts on communities was seen as local weather events caused insurance to be withdrawn from some markets. For example, universal flood insurance was withdrawn in the UK after no increase in flood defence investment.	Property prices collapse as insurance is no longer available for natural disasters. Certain cities are regularly hit by flood. Rural areas in Southern Europe, mid-US and Latin America are regularly hit by droughts and wild fires.

Table describing key outcomes.

[775] http://news.nationalgeographic.com/news/2010/100930-freshwater-river-map-security-risks/

Long term projection

Pessimistic predictions: *Some local long term declines in developing & emerging countries (water and food availability and penetration of new technologies into certain markets pushing back development gains) but major global economic decline averted*

Optimistic predictions: *Major global economic decline averted and fewer regions impacted by local declines*

6.3.3 Regulation driven change

Governments operated on a long term basis and regulated the stock of resources rather than the flows. Markets remained short term in focus and priced resources based on flows. Change was driven through increases in taxes on certain resources and banning the use of other resources (or phasing them out).

The market responded to regulatory change in a short term way and therefore it was not always possible to predict the outcome of policies that were implemented and unintended consequences were seen. Innovation was not driven as effectively as could be with sporadic changes to new technology availability leading to breakthrough changes in markets and highly volatile energy prices. The feedback from market change to policy development was not effective and more often than not policy failed to deliver on key objectives.

Certain resources were managed while others were over-exploited and the impact on society was uncertain with some key societal services being ineffectively delivered.

Economic growth

Governments around the world, in particular in Europe, were increasingly concerned about the volatility of prices of commodities and energy. Independent oil companies started to declare bankruptcy more regularly[776] as increased costs of exploration linked with volatile prices and environmental legislation made it difficult to plan and attract investment. A major shock in oil prices led some governments to re-nationalise their oil companies. This occurred alongside the re-nationalisation of water companies (in countries where they had been privatised) following further droughts and extreme flooding that caused widespread condemnation in the press.

As energy prices continued to be volatile more energy related industries became nationalised creating large monopolies within countries[777,778]. Given limited government funding very often the nationalisation was done 'in the public good' and significantly under market value. Therefore this resulted in significant losses across the stock markets and by mid century most private pension funds were significantly under-funded.

Government regulation banned the use of certain resources over time, attempting to give industry a 5 year timeline to strategically invest in alternatives (this policy was based on the Japanese Top Runner programme[779] as well as using forward procurement standards for

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[776] http://www.forbes.com/sites/christopherhelman/2012/08/18/as-atp-oil-files-for-bankruptcy-ceo-blames-obama-for-companys-collapse/

[777] http://www.procurement-iu.com/blog/2012/4/is_resource_nationalisation_sweeping_across_latin_america

[778] http://www.independent.co.uk/news/world/africa/call-for-nationalisation-of-south-african-resources-8096846.html

[779] http://www.futurepolicy.org/2719.html

government contracts[780]). This led to large increases in renewable technologies being deployed in the transport industry and energy industry. However, by mid century critical resources that some of these new technologies relied upon were seen to be in limited supply or required significant investment in unstable countries[781]. Other sectors and resources that had not been covered in the new regulation also reached limits and undermined economic growth in some sectors. Therefore, industrial growth stalled and there were a significant level of stranded assets (assets no longer commercially viable) within the economy.

A further oil shock was seen after national oil companies, who had previously over stated their reserves, having to severely reduce production[782]. As the majority of energy and resource investment was now owned by national governments this reduction in income from a much lower production base meant a number of countries could no longer service their national debt repayments and defaulted resulting in the global economy going into long term decline.

Social cohesion and security

Mortality rates slightly declined in developed countries due to a reduction in cold winter deaths as a result of climate change. Urbanisation continued globally coupled with increased investment in city infrastructure. Birth rates in urban populations remained low and so global populations peaked at 8 billion[783] and then started to decline by the middle of the century.

By the middle of the century the pressure on government spending due to nationalised industries combined with an ageing population led to a significant increase in the pension age[784]. Industrial action was seen much more regularly however at best this merely delayed the introduction of increases in pension age. By the end of the century retirement had all but vanished and pressure switched from pension provision to social security and unemployment support.

The impact of climate change was limited somewhat due to a new international treaty that came into force in 2020[785]. However, the restrictions on energy sources that this put in place did not stimulate a corresponding increase in short term private sector investment in a low carbon energy infrastructure resulting in rolling black outs becoming common place by the middle of the century[786] while alternative technologies were rolled out slowly. This resulted in significant impacts in health care provision.

There was a significant shift in the political landscape of countries with the more extreme parties gaining favour. These local shifts cause some regional tensions and mass migration between countries is seen after the middle of the century.

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[780] http://www.cpsl.cam.ac.uk/Business-Platforms/The-Prince-of-Wales-Corporate-Leaders-Group-on-Climate-Change/UK-Procurement.aspx
[781] http://quantumsp.com/en/solar-energy/a-comparison-of-pv-technologies/
[782] http://www.time.com/time/world/article/0,8599,2048242,00.html
[783] Rander, J, (2012), *2052: a global forecast for the next forty years,* Chelsea Green Publishing
[784] http://www.irishtimes.com/newspaper/finance/2012/0928/1224324535454.html
[785] http://www.telegraph.co.uk/earth/environment/climatechange/8949099/Durban-climate-change-the-agreement-explained.html
[786] http://www.guardian.co.uk/world/2012/jul/31/india-blackout-electricity-power-cuts

	2030	2080
Corporates	Limited investment in alternative technologies with increased investment in higher cost resource extraction seen over the short term. Water companies re-nationalised where they had been privatised.	Energy and water companies all nationalised and the majority of commodities and food supply now managed by governments. Global economic decline occurred mid century following on from a second oil shock. Few large companies remain.
Governments	Short term confidence in government returns. Increase in government debt issued to prepare for purchase of key resources.	Governments borrow from each other as there is no private enterprise at scale (pension funds having been re-absorbed into national accounts). However, strategic partnerships between similar governments arise causing increasing political tension globally.
Society	Local water availability and flooding are better managed.	Climate change is better managed although impacts still seen at local levels. Government insurance now regularly used in some areas causing cities to go bankrupt. Ghettos and shanty towns around all major cities.

Table describing key outcomes.

Long term projection

Pessimistic predictions: *Some local long term declines in all countries (technology fails to change fast enough) and long term global economic decline follows as market failures are widely seen and cannot be managed*

Optimistic predictions: *Fewer local declines but global economic decline follows as market failures are seen and cannot be managed (possibly delayed from the pessimistic prediction)*

6.3.4 Consensus driven change

Governments and markets operated on a long term basis by pricing and regulating the stock of resources rather than the flows. Government and market decision makers worked closely together to develop long term policy frameworks and market mechanisms that enable and build on market innovation. Global population peaked at around 8 billion before the middle of the century.

Prices were less volatile and reflected longer term changes in availability of resources making investment into innovation easier and government regulation supported the deployment of alternative technologies to ease market transition. Steadily increasing prices combined with supportive regulatory environments enabled new business innovation around waste management and a dramatic increase in recycling and reclaiming resources from waste streams[787] was seen which alleviated some of the resource constraints.

The transition from certain resources was managed so that prices for services (for example, energy) are implemented equitably to ensure appropriate access for all. There was a significant shift towards long term investments in infrastructure.

Economic growth

An international legal framework is negotiated by 2020 under the United Nations[788] and covered climate change and global resource management. Progressive corporate lobbying[789] ensured that private sector risk exposure, with appropriate timescales for investments, were included in the international treaty. Water was included as an important local issue.

Price volatility was dramatically reduced as long term planning around resources increasingly became common place within industry. Steadily rising taxes on scarce resources created more of a short term incentive for companies to invest in alternatives or recycling and revenue from those resources was used to invest back in industry towards the development of alternatives. Some of the increased revenue was used to ensure accessibility to resources through pro-poor initiatives although the effectiveness of these were regularly challenged by developmental charities.

Investment into food productivity increased and land purchases continued. However, pressures to ensure land remained productive over a longer period, combined with differing regional impacts of climate change on food productivity[790], resulted in overall growth of food globally stagnating by the middle of the century. This led to pressure on those regions able to increase food productivity and so the US and other countries lowered their requirements for biofuel production[791] to allow for more food production[792]. This also led to an increase in investment in alternative energy sources.

Towards the end of the century private enterprise had shifted investment towards a lower carbon model and governments had significantly invested in the infrastructure required to support these new technologies in particular in grid technologies. Some climate change impacts were seen and governments also invested in flood defences and water management systems[793].

The insurance market for extreme weather events expanded dramatically.

By the middle of the century the global economy contracted at a similar rate to the overall population decline. However, there were significant differences between countries with some seeing more rapid declines (predominantly those classed as developed countries at the beginning of the century) and others seeing growth over the medium term until imbalances

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[787] http://www.thecirculareconomy.org/
[788] http://www.telegraph.co.uk/earth/environment/climatechange/8949099/Durban-climate-change-the-agreement-explained.html
[789] http://www.ft.com/cms/s/0/95098764-b654-11e1-a14a-00144feabdc0.html#axzz27l95v1Fs
[790] Rosenzweig, C & Parry ML, (1994) *Potential impact of climate change on world food supply,* Nature, 367, p133-138
[791] Rathmann R, Szklo A & Schaeffer R (2010), *Land use competition for production of food and liquid biofuels: an analysis of the arguments in the current debate,* Renewable Energy, 35, pp14-22
[792] http://www.ft.com/cms/s/0/12dbb322-e48d-11e1-affe-00144feab49a.html
[793] http://www.environment-agency.gov.uk/research/library/publications/108673.aspx

between the major economies were no longer seen (the world became more equitable at country level for major economies). Some countries remained poor.

Social cohesion and security

Climate change impacts were not as severe as had been feared following the international treaty and subsequent investments in low carbon technologies[794]. Therefore, the expected impacts from climate change were lower than had been feared.

Civil unrest was seen in some cities in the developed world as the international treaty is negotiated and people reacted against what was perceived as limits on economic freedom[795]. In particular restrictions to consumption patterns and the increased need for investment into long term infrastructure was seen as a ‘green conspiracy’.

A small number of countries held elections at critical times which resulted in a significant shifts in the political make up. This resulted in some countries setting up trade barriers leading to long legal cases with the World Trade Organisation[796]. These trade ‘wars’ impacted access to global resources and large increases in inflation caused further civil unrest. Other countries moved to new, longer term forms of government. For example, some countries extended their election and political cycles (moving to 10 year time horizons) while others adopt a form of government where elected politicians acted more as a non-executive board to an executive civil service who had the mandate to develop long term policies. However, with no alternative solutions the major economies transitioned to a more equal footing.

Renewable energy became the dominant source of power globally. Infrastructure in some countries supported storage of power to allow continuous availability. This was not possible everywhere. Therefore, in some countries, a new flexibility in society emerged to manage intermittent power availability.

By the middle of the century the majority of citizens saw an increase in wellbeing predominantly driven by the increase in an overall sense of security and a more equitable distribution of resources globally.

Global measures of economic success were changed.

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[794] http://www.iigcc.org/__data/assets/pdf_file/0017/15281/2011-Investor-Global-Statement-FINAL-NOT-EMBARGOED.pdf

[795] http://thf_media.s3.amazonaws.com/1997/pdf/bg1143.pdf

[796] http://www.wto.org/english/res_e/publications_e/wtr10_e.htm

	2030	2080
Corporates	Strategic investments in longer term technologies and infrastructure seen. As companies respond to international agreements the cost of resources rises and therefore there is a rebalancing of corporate accounts.	Global infrastructure is set up for the long term management of renewable resources with a small input of key resources that are yet to be substituted. End of life re-use is a major industry and a new insurance market opened up in this space.
Governments	Governments start to operate on balanced budgets as they looked towards lower growth rates.	All governments operate on longer political time frames.
Society	Some extreme weather events seen.	Some local impacts from climate change but these are managed through a combination of government investment and private sector insurance.

Table describing key outcomes.

Long term projection
Pessimistic predictions: *Some local declines (water and food) however global economy stabilises based on new technology deployment*

Optimistic predictions: *Fewer local declines and global economy stabilises*

7. Impact on financial institutions and implications for actuaries

This chapter investigates how a future where economic growth is constrained by limited resources might affect actuarial models. The question being investigated is "what might happen to a long-term financial arrangement such as a pension scheme if future growth was limited by resource constraints?" We are not investigating the likelihood of future growth being constrained in this way, but investigating what might happen to the financial arrangement if it were. The question is investigated by developing a set of plausible scenarios which reflect a future world where growth is limited. We are not assigning any probabilities to any of these scenarios, the criteria being that each scenario is plausible and internally consistent.

If we are entering such a future resource-constrained world, then there is no way of knowing with any certainty what the impact on financial variables might be. The scenarios are developed around plausible narratives of what might happen, they are not in any way predictions. The purpose of this exercise is to investigate what the range of effects might reasonably be of a "limits to growth" world on a pension-type arrangement, and whether it would be different to a scenario where the future is broadly in line with the past.

Actuaries advise a number of different categories of financial institutions predominantly insurance (both life and non-life) companies and pension schemes, but also banks, and a range of clients on enterprise risk management, health care and investment issues. This chapter concentrates on pension schemes; which have been chosen because they usefully illustrate the kind of considerations actuaries need to make; pension funds are particularly appropriate because limits to growth is a long term trend so has the most significant implications for long-tailed business such as pensions.

Life insurance is likely to be affected in a similar fashion as pensions. The implication for non-life business is not considered here as it tends to be shorter tailed. That is not to say that there will be no impacts on non-life insurance, but these affects are complex. The impact of climate change, for example, has been covered extensively elsewhere. The area that has been most studied is the potential impact of increased weather related claims[797]. However a previous actuarial paper[798], identified that the risk from climate change is a combination of the increased claims combined with falling asset values, increased capital values, declining new business and reputational risk. These risks will be magnified by resource constraints issues.

Of the other sectors, such as risk management and investment, it is highly likely that resource constraints could impact on these areas. This section is a demonstration of how resource constraints might impact an example of an actuarial model, and the thought process that an actuary might undertake to integrate resource constraints. One example, namely modelling of a pension scheme is therefore worked through in detail, rather than try and comment on all possible areas that actuaries are involved in. It is hoped that actuaries working in these other fields will consider the impact on other models, assumptions and hence advice – it is not the intention, or possible, that this report could possibly cover all areas of actuarial advice.

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[797] See for example CII (2009) *Coping with Climate Change risk and opportunity for insurance* Chartered Insurance Institute

[798] Bruce et al (2007) *The Impact of climate change on non-life insurance* GIRO

The scenarios we have chosen have economic growth as the driving (exogenous) variable, and are bounded as follows: the upper bound for growth is "business as usual", that is where the future is broadly similar to the past, the assumption is that all resource constraint scenarios have a negative impact on economic growth. This does not represent a full range of scenarios, the future could conceivably give rise to higher economic growth, for example due to technological breakthroughs as has been proposed by a number of prominent futurists[799]. These scenarios are excluded not because they are impossible, but because they are outside the confines of the phenomena we are investigating and would serve to confuse the picture. The lower bound is a collapse of the financial system; in this world there is unlikely to be functioning financial markets and so the analysis would be meaningless. The scenarios investigated all implicitly assume that any harm caused to the economy is not severe enough to entirely destroy financial markets, and are therefore not worst case scenarios.

The chapter is split into 3 sections, 7.1 considers how resource constraints leading to limits to growth might be taken into account in setting actuarial assumptions, based on this discussion 7.2 develops scenarios and runs those scenarios through a model of a simplified pension scheme. The model is no different to a normal actuarial model of a pension scheme, except that the assumptions/scenarios consider what might happen in a resource constrained world.

This chapter focuses on pension schemes – and therein the specific area of assumption setting and ongoing funding and 'solvency'. It should be noted that actuarial advice goes beyond just funding issues, some of which is touched on in the last section of the chapter.

This chapter considers a financial institution based in the UK, or a UK-like country, which has some of its assets invested internationally. Whilst the intention of the report is not to be geographically limited, the purpose of this chapter is to give an example and work through the thinking that an actuary might undertake to integrate resource constraints into setting assumptions. The thought process would be similar for an institution located in another location, but might involve some local variations.

7.1 Key variables – impact of resources on actuarial assumptions

If economic growth is limited by resource constraints, this could be reasonably expected to significantly affect future financial outcomes, for example inflation and investment returns. It could also have significant effects on demographic factors, for example if the economy could not afford to pay for health care then mortality rates might be impacted. If these future outcomes are indeed affected, then the assumptions that actuaries use should take into account these future developments.

This section discusses how actuarial assumptions might be affected by resource constraints. The impact of resource constraints on economic growth and hence on financial variables, and even more so on demographic variables, is highly speculative and cannot reasonably be predicted with any certainty. The approach taken is firstly to briefly consider the factors which affect the assumptions; these factors are complex; there are often conflicting theories, for example on what causes inflation, and these theories have changed over time. For the purposes of this report, the main factors are summarised as briefly as possible.

[799] See for example Kurzweil, R (1999) *The singularity is near* Viking

Having established the factors that determine the assumption, we then investigate how resource constraints might alter the assumption. This discussion is by no means meant to be exhaustive, but represents the approach that an actuary might take to investigate further. Where possible, historical examples are brought in to illustrate and inform the discussion.

The overall general factors that might be caused by resource constraints that may affect actuarial assumptions are (this list is by no means exhaustive):

1. Reduced economic growth caused by resource constraints and reduced confidence
2. Reduced access to many commodities, and hence increased prices or lack of availability
3. A series of price shocks caused by 2)
4. Reduced international security and coordination as countries compete for scarce resources
5. Repression of investment returns as governments seek to direct investment into sectors that are required to make the economy more resilient
6. Increased differential of investment returns in different countries that are starting from different allocation of resources, efficiency and debt levels
7. Lower growth could lead to increased bankruptcies as heavily indebted countries, companies and individuals are unable to pay their debts due to the lack of growth
8. Warmer temperatures and more climate disruption e.g. sea level rise, cyclones, droughts and flooding.
9. Increased domestic and international social tension brought about by inequality and hardships exacerbated by resource constraints, climate disruption and lower economic growth.
10. Possible changes to life expectancy and morbidity caused by climate change, lack of access to resources, or changing ability to afford medical care.

In the discussion below, the assumptions are grouped into 3 broad categories, namely discount rates (this includes interest rates and investment returns), inflation (including salary and prices), and demographic factors (mortality and morbidity).

Actuarial assumptions are not set in isolation but as part of an actuarial basis which should be internally consistent. The relationship between variables (for example salary growth and investment return) is usually more stable than the absolute value of any given variable. These relationships are therefore of particular importance.

In previous chapters, we have seen how the action of society, either the private sector, government or both has a large determinant on the magnitude and impact of resource constraints on the economy and society. The same is also true at the financial and demographic level. How society reacts will be a major determinant of outcomes. This can be in a number of ways, but some of the most important are:

1. The reaction of monetary authorities to increases in commodity prices – this will determine whether increases in commodities result in general inflation.
2. Society will need to invest more and consume less[800] – the way this is achieved will determine investment returns both absolute and relative to wage growth.

[800] J. Randers, 2052: A global forecast for the next 40 years, 2012

3. Financial repression – in certain circumstances governments could pro-actively or re-actively intervene in allocating investment, to react to a perceived or actual threat. This could constrain investment returns and wage growth.
4. Social Upheaval - increased resource prices will cause income re-distribution, possibly leading to increased social tensions and resource constraints will be unequally distributed between countries, with some countries lacking access to key resources. This could lead to international tension, with potentially reduced trade, economic activity or possible breakdown in security. How governments react will be crucial - a financial consequence could be increased inflation as governments are tempted to inflate away debt to reduce social inequality, and also increased interest rates due to increased uncertainty. Increased military spending is another possibility.
5. International investment – many institutions rely on returns generated internationally both directly or indirectly (via domestically listed entities operating internationally). Some regions' economies will fare better than others.[801] However, the extent to which domestic entities can benefit relies on continued international cooperation and willingness of investee countries to attract foreign investment.

7.1.1 Discount Rates

Discount rates have many different uses, but this paper's focus is on the long term, and there are essentially 3 different applications of discount rates for decision making and measuring purposes, which affect the choice of rate and methodology used. These are:

Matched calculation: this is where discount rates are used to calculate a liability "by reference to market instruments (or models to simulate market instruments) which seek to *match the characteristics of the liability cash-flows*"[802]. This is used particularly in transactional work and in pensions, insurance, finance and investment and enterprise risk management. The discount rate is therefore determined by market instruments, if a liquid and transparent market exists, or an estimate of what those rates might be if those rates do not exist.

Budgeting calculation: the discount rate is used to determine a liability depending on how that liability is going to be financed; here the discount rate is the expected return from assets which are used to meet the liabilities. "The discount rate usually retains a much larger element of embedded risk, often incorporating credit for an equity risk premium, or making an implicit allowance for the riskiness of the future cash flows, or using a hurdle' rate, which assumes high returns to compensate for higher risk"[803].

Social time preference: this is the rate at which society values the present compared to the future, and is generally used by government for decision making where spending or investment at different times have to be compared. The discount rate is made up of two components, firstly the rate at which individuals discount future over present consumption, and secondly a rate derived from the fact that consumption is assumed to increase, so consumption now is more valuable to consumption in the future. The UK's treasury use a rate of 1.5% for the former effect and 2% for the latter, making a total rate of 3.5%. In addition an extra loading can be added to reflect risk and uncertainty (HM Treasury).

[801] ibid.
[802] C Patel and C Daykin, *Actuaries and Discount Rates, A discussion Paper* The Actuarial Profession, 2010
[803] ibid.

For longer term projections, the use of social time preferences has been challenged on ethical grounds (most notably by Stern (2006)), a challenge which has been widely accepted. In particular where irreversible inter-generational wealth transfer from future generations to the present applies it is not ethical to use social time preferencing as this will undervalue the damage/benefit to future generations who are not currently represented.

Possible impact of resource constraints

There are 3 separate discount rates referred to above, which will be affected differently:

Matched calculation: is effectively the market rate of bond yields for a given duration. The "risk free rate" is usually taken as a government bond yield, for discounting pension liabilities corporate bond yields are used. The latter is therefore determined by government bond yields plus the spread. Long dated government bond yields in theory are influenced by expectations of future inflation, general levels of uncertainty and, latterly, government's creditworthiness (both actual and perceived). All of these are likely to change in a resource constrained world. The credit spread is likely to increase, although in the long term it is not necessary that corporate bond yields will always be used to discount liabilities. However, as we tend towards increasingly extreme scenarios, there are no risk free investments to match cashflows. This means that there is a risk of the cash-flows from assets not being paid, and hence the assumed returns should be lower.

Budgeting calculation: this is given by expected investment returns, which are determined by the "risk free" yield as described above and a combination of equity risk premia and credit spreads. All of these are predicted to increase, however this does not mean that returns can be expected to increase; in the past where conditions have been relatively benign and stable, the risk has ended up with positive outcomes. In a more unstable world with declining economies, this risk might inevitably give rise to negative outcomes. Therefore the actual returns could be expected to reduce. An actuary or other modeler with perfect foresight would therefore predict this, however, in the past backward looking models have been used and therefore discount rates used might be expected to overstate future returns.

Social time preference: In the formulation given above, this is made up of how individuals discount the future and an assumption that consumption now is more valuable, as we will be wealthier in the future. The latter assumption breaks down in a resource constrained world, so this part of the formulae would reduce, possibly becoming negative. The impact of resource constraints of the former may also change but less predictably. If we are going into a world of greater uncertainty, people might be more inclined to spend today rather than save (tomorrow they may be dead!). This happens in unstable poor countries where interest rates tend to be high. The long term inter-generational calculations may also change. If the future is increasingly uncertain and society and the economy might go into long term decline, then it is rational to spend more today, as there may be nothing to spend in the future: this could happen as a result of a break down in trust.

In all three cases, an important consideration is the reaction of government, in terms of both monetary and fiscal policy. However, the reaction of government and the effect of that government policy is unpredictable, especially on long-term returns, which this paper is concerned with.

In gathering evidence on what discount rate assumption should be used in a low growth/resource constrained future world, it is useful to look at historical incidences of when certain characteristics of what might happen have already occurred.

Example 1: resource constraint led to low economic growth: 1970s oil crisis
An illustrative historical event was the oil crisis in the 1970s. This term is mainly used to describe the effects of 2 events, an oil embargo imposed in 1973 by OPEC and the Iranian revolution in 1979, both of which caused oil prices to spike: in the 1973 crisis oil quadrupled overnight from $3 a barrel to $12 a barrel, and in the latter from $16 per barrel to $40 per barrel[804]. A combination of circumstances (for example the US coming off the gold standard in the early 1970s) combined with these two events are widely blamed for a turbulent economic decade.

Figure 66 outlines the impact of these events on interest rates[805]. This example is relevant as a resource event (lack of access to oil) led to reduced economic growth for a period of time.

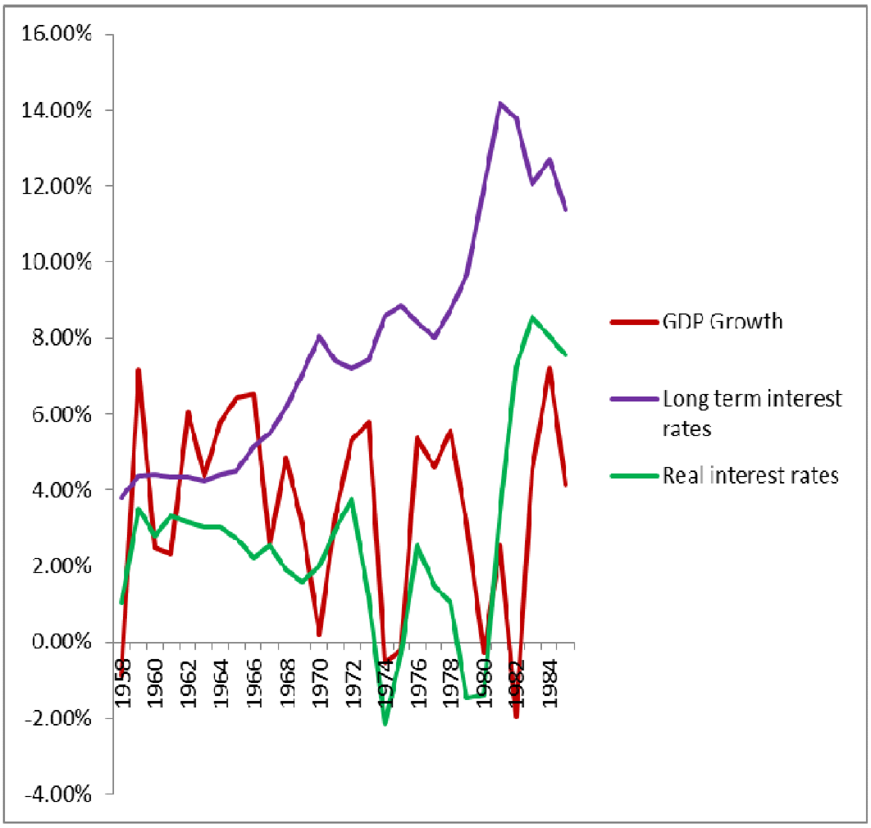

Figure 66: Impact of 1970s oil crisis on US economy

Figure 66 shows that before the crisis interest rates were stable. Following the crisis there was an increase in nominal interest rates, whereas real interest rates start oscillating. There appears to be a close relationship between GDP growth and the real interest rate.

[804] Mouawad, Jad (2008) *Oil Prices Pass Record Set in '80s, but Then Recede* New York Times
[805] Data provided by Societies of Actuaries in Ireland

Example 2: long period of low economic growth: Pre-industrial revolution in UK

Prior to the industrial revolution, which started in the UK in the late 18th century, economic growth was low by modern standards. In some senses the economy was resource constrained as people had not yet harnessed fossil fuels, so the economy was mostly powered by agricultural produce (i.e. energy from the sun harnessed through photosynthesis, which is then eaten by animals and people) which is limited by the amount of land under cultivation[806].

Figure 67 looks at a period of UK history prior to and after the industrial revolution[807].

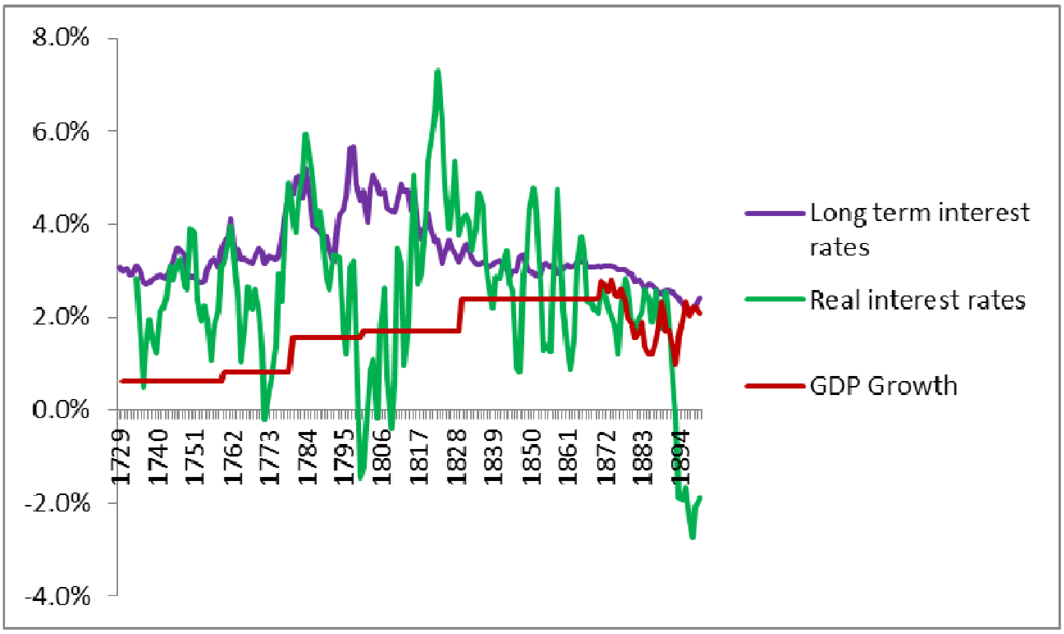

Figure 67: Comparison of interest rates pre and post industrial revolution in the UK

Figure 67 shows that growth was indeed low prior to the industrial revolution, as it gradually climbed to modern levels. However, this does not appear to translate into low real interest rates prior to 1800 (the increase in nominal and reduction in real rates at the end of the 18th century may be due to the Napoleonic wars). It may be that this situation is no longer replicable, in the 18th century the government was small by comparison to today with low levels of debt. This debt could later be repaid as the tax base expanded and the economy grew. However, current debt levels are now large compared to the economy and it would be difficult to see how interest much higher than growth rates could be paid back.

[806] See Morris, I (2010)
[807] Data provided by Societies of Actuaries in Ireland

Example 3 Low economic growth: the Japanese "lost decade"

Japan's economy overheated in the 1980s, leading to a massive property bubble. When this bubble burst, Japan entered a period of low growth[808]. The impact on interest rates is shown on Figure 68[809].

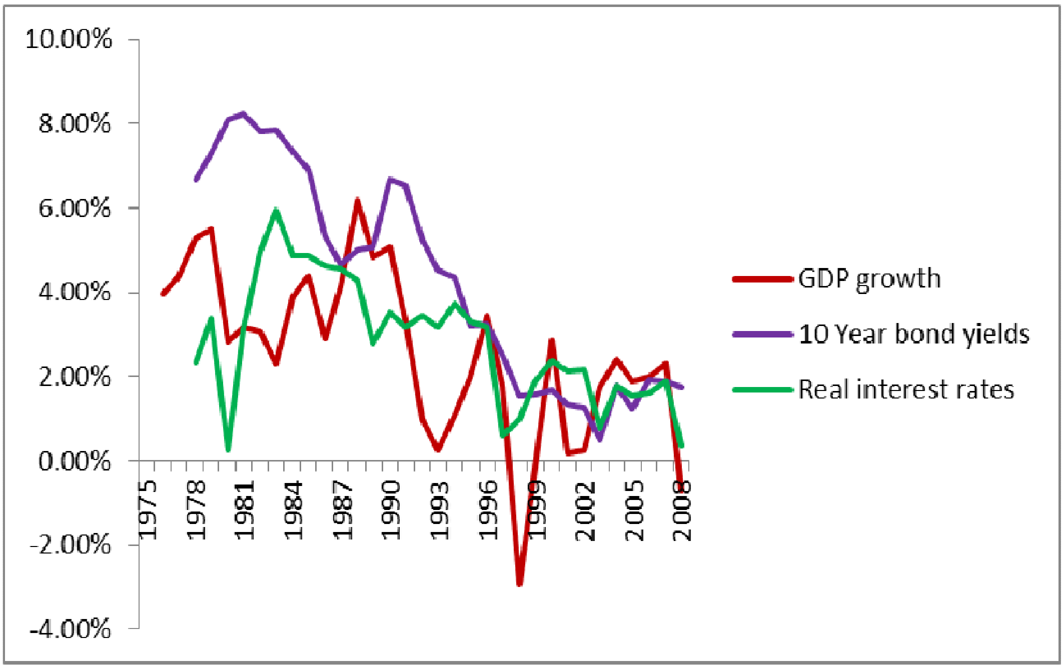

Figure 68: Japanese "Lost Decade"

The lost decade was not caused by resource constraints but it was a long period of low economic growth. Figure 68 shows this coincides with reducing and ultimately low real government bond yields.

Example 4 Increased investment and suppressed returns: UK during World War II

To meet the challenge of a resource constrained world, society is likely to have to reduce consumption and increase investment. This might come about pro-actively , for example by investing heavily in renewable energy, or re-actively, for example by flood defenses or increased military spending in response to severe climate change or worsening international security.

This re-engineering of the economy has happened before, normally in times of war. Figure 69 is an example of the UK economy during World War II[810].

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[808] Werner, R, New paradigms in macroeconomics- solving the riddle of Japanese macroeconomic performance Palgrave Macmillan, 2005

[809] Data from http://www.measuringworth.com/datasets/japandata/result.php

[810] Data provided by Societies of Actuaries in Ireland

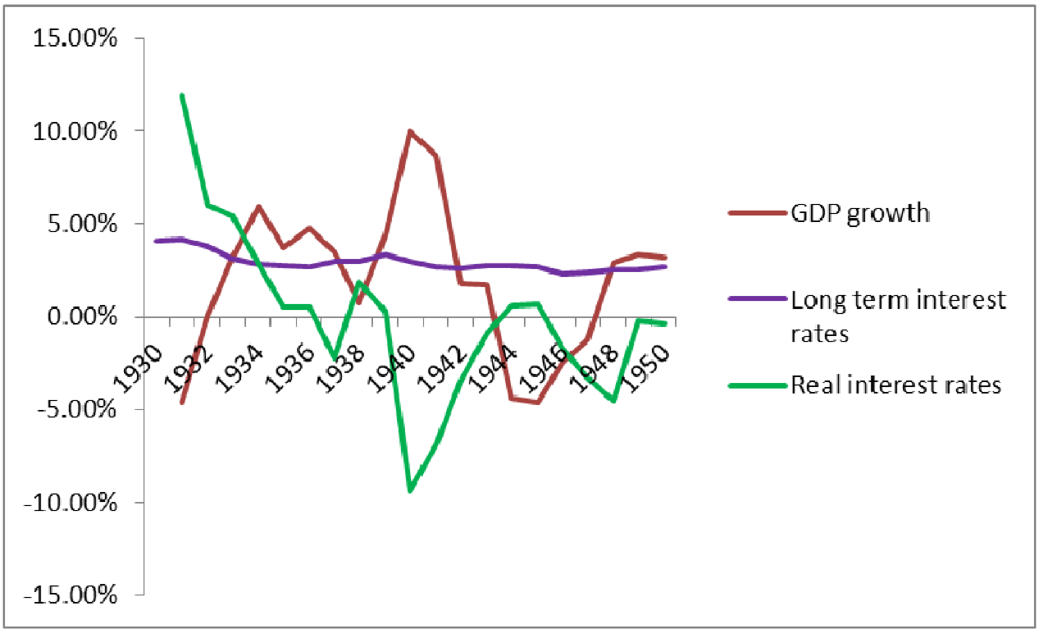

Figure 69: UK Second world war experience

Figure 69 shows that the UK economy grew strongly during the war period (1939-1945), after low or negative growth in the 1930s. However, this was not reflected by increased returns, these were suppressed during the war and were actually negative. Financial repression is a method often employed by governments in times of duress[811].

Impact on discount rates and investment returns

Long-term investment returns (across portfolios) will be determined by a number of factors, however, these must be distinguished from the factors that affect short-term, portfolio specific returns. The primary driving factor for real returns are economic growth, secondary factors include tax and regulatory issues, fiscal and monetary policy, the relative returns to capital and labour and the structure of the economy (for example if this structure changes so that the relative advantage of debt against equity finance alters).

The primary effect of resource constraints would be if they caused a reduction in economic growth, which would have a direct impact on investment returns. Figure 68 shows that lower growth led to lower returns in Japan in the 1980s and 90s. However, this effect might be complex: the UK currently has high levels of debt (492% of GDP including financial, corporate, household and government[812]) as have many other developed countries, so with lower long term growth rates, this debt burden will increase if the interest payments are greater than the rate at which the economy grows and eventually become unsustainable. What would subsequently happen is unknowable, but could result in major economic losses.

Many of the other effects described above may lead to reduced economic growth but could also have independent negative impacts on investment returns. Reduced access to many commodities (including energy and water) and subsequent price shocks could lead to many companies and even countries becoming non-viable leading to bankruptcies, nationalizations or reduced profitability, as happened in the 1970s oil crisis (Figure 67). Government's reaction could be to introduce capital controls and/or financial repression to mandate financing for necessities, which could lower investment returns – as happened in

811 CM Reinhart & KS Rogoff, *This Time Is Different*, 2009

812 Roxburgh, C et al, *Debt and deleveraging* McKinsey Global Institute, 2011

Wold War II (Figure 69) and in many other circumstances following debt crisis[813]. Also the impact of climate change could lead to increased losses from natural disasters which could impact the capital stock and financial institutions (especially insurers) which could lead to reduced returns, as could the resultant second and third order affects from impacts in more vulnerable countries[814].

Currently most UK institutions have significant exposure to overseas investments both directly and indirectly (for example most UK listed companies have overseas operations, suppliers and companies). So even if the UK were to suffer much reduced returns, investments abroad in countries that were less affected could compensate. However, a reduction in international co-operation and security or the imposition of credit controls could put a stop to this.

The impact of climate change on severe weather events has been well documented elsewhere (see for example IPCC (2012)), in the form of increased storm damage, increased flooding, increased subsidence and droughts. These will obviously have an impact on insurance companies, especially on re-insurance companies. However, these companies also have the most advanced understanding of risk and therefore can either price accordingly or not write vulnerable business, if they are allowed to do so by regulators. Therefore insurance may become unavailable, and the most vulnerable (economic) sectors are ones with vulnerable property assets, for example sea-side power plants.

Catastrophic risk could be more widespread than this. So for example, water is often not a large cost for a company, but if access to water is stopped, then the company may no longer be able to function. There may be many other supply chain risks which could be catastrophic if no substitute is available for a component.

Conclusions on interest rates:

- There is evidence to suggest that lack of access to resources, especially energy, can lead to low economic growth.
- Low growth can cause low real interest rates and asset returns
- Nominal interest rates are not predictably affected by low growth
- In times of duress, governments might supress interest rates and investment returns

7.1.2 Inflation – prices and wages

Price Inflation, the rise in the general level of goods over time, is an important assumption for actuaries, as some of the valued liabilities will be inflation linked, for example non-life insurance losses will typically increase with inflation and many pension benefits are linked to inflation.

Wage growth is a crucial assumption in determining liabilities of defined benefit pension schemes as the level of benefits are determined by future salary growth of members whose pension is linked to their final salary. Wage growth is linked to two factors; firstly prices inflation, in general wages and prices are mutually dependent (if prices increase then workers usually demand or expect higher wages, and if wages increase then the cost of supplying goods increase so prices increase). In addition as the economy grows then wages

[813] CM Reinhart & KS Rogoff, *This Time Is Different*, 2009
[814] Silver, N Cox, M and Garrett, E, *The Impact of Climate Change Overseas on the UK Financial Services Sector,* Government Office for Science, 2010

generally increase because the increase in wealth from economic growth is split between capital and labour, this split could change with time, but generally only within certain parameters. The salary increase of an individual is also affected by their career progression, but this is usually dealt with as a separate assumption and is a function of their employment, not the overall economy.

Actuaries use a number of techniques for setting the inflation assumption, for example looking at past trends or taking the differential between inflation linked and fixed bond yields. The inflation assumption alone is often of lesser importance than the difference between inflation-linked benefits and other assumptions, such that “real yields” are often used. So, for example, if a pension scheme pays inflation-linked pensions, then the real discount rate used is important – namely the yields in excess of inflation. The inflation assumption here is often nominal, provided the excess of yields over inflation do really remain constant.

There is a vast array of literature on what causes inflation which cannot possibly be effectively summarised here. The predominant economic theory is the quantity theory of money; that is that the speed of the increase of the supply of money determines the level of inflation. There are differences of opinions over whether inflation fluctuates away from this only for a very short time or for longer more significant periods, with the two dominant schools of thought being monetarist and Keynsian.

Monetarists: believe that inflation is predominantly caused by rate of the increase of the money supply, succinctly expressed by Milton Friedman “Inflation is always and everywhere a monetary phenomenon.” A variant of the monetarist position is rational expectations theory; that economic agents will make decisions based upon how credible the monetary authority’s position is which affects inflation. So, for example, if workers believe that the monetary authority’s anti-inflation policies are not credible, they will argue for a high wage which then determines inflation.

Keynsian: accept that inflation is ultimately caused by the increase in the money supply, but there can be significant variations away from this except in the long-run, and, in the words of Keynes “in the long run we are all dead”. Inflation can be caused by “demand-pull” where increased spending leads to inflation because aggregate demand exceeds the economy’s potential output, “cost-push” where a drop in aggregate supply (for example due to an oil shock) leads to an increase in the price of these goods, and “adaptive expectations” which results from a vicious circle of spiraling wage demands leading to increased inflation which leads to higher wage demands, and so on.

An alternative theory is the “cost-push” theory of inflation, which proposes that inflation is caused by an increase in the price of goods or services when no alternative is available, an idea that is strongly challenged by monetarists.

Possible impact of resource constraints

A series of economic price shocks from lack of availability of resources would lead to short-term inflation. As we have identified, oil is one of the crucial depleting resources, and hence is the most likely candidate to cause price shocks. Oil is at the moment, the only credible transport fuel, so if the price of oil increases so does the price of everything else. According to the cost-push theory, this will lead to inflation. According to the monetarists, inflation will only occur if the rate of the increase in money supply was speeded up, which is in the hands of the government. However, governments would be tempted to increase the money supply as the rise in commodity prices would suppress growth, make debts harder to pay off and change the distribution of wealth within the economy. Also a series of price shocks would lead to a change in rational expectations.

The impact of resource constraints cannot be predicted with any certainty on real wage increases. As the economy as a whole has to dedicate more (financial) resources to (non-renewable) resources, this could mean that there would be less resources paid to labour. Alternatively, because resources are more expensive, that might make returns to certain forms of labour greater. Workers with a pension might be a select, and therefore relatively elite group, who could (financially) benefit from the scarcity of resources as their skills become more valuable. Hence wage inflation could also increase under certain circumstances, depending on how events play out.

Example 1: resource constraint led to inflation 1970s oil crisis
Revisiting Example 1, figure 70 shows the impact of the 1970s oil crisis on price and (real) wage inflation in USA.

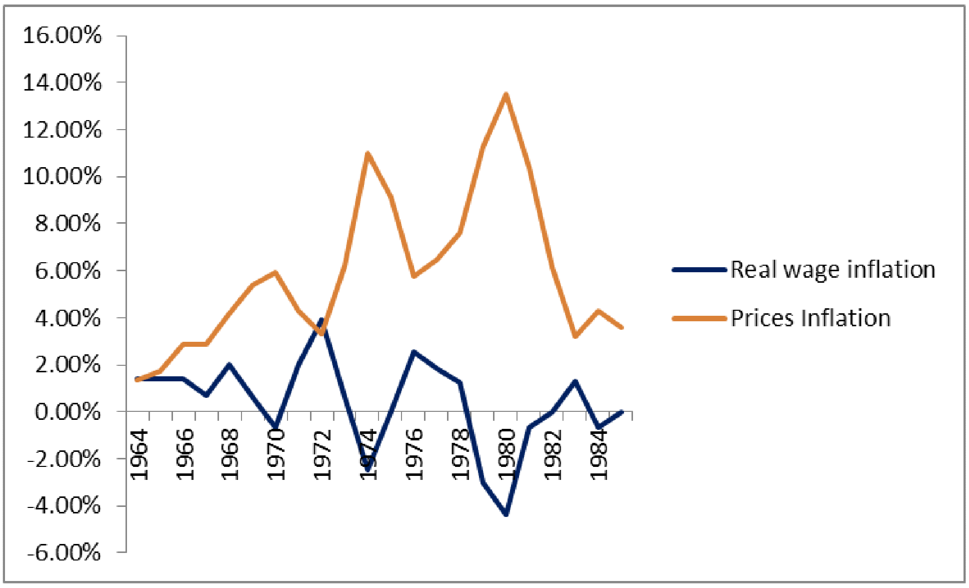

Figure 70: Impact of 1970s oil crisis on inflation in the US

The results are quite striking, in the decade of the crisis, prices inflation attained high levels whereas real wages stagnated.

However, there is not necessary a correspondence between high oil prices and inflation, if we look at longer data series as shown on figure 71[815].

[815] Data from http://inflationdata.com/inflation/Inflation_Rate/Historical_Oil_Prices_Table.asp

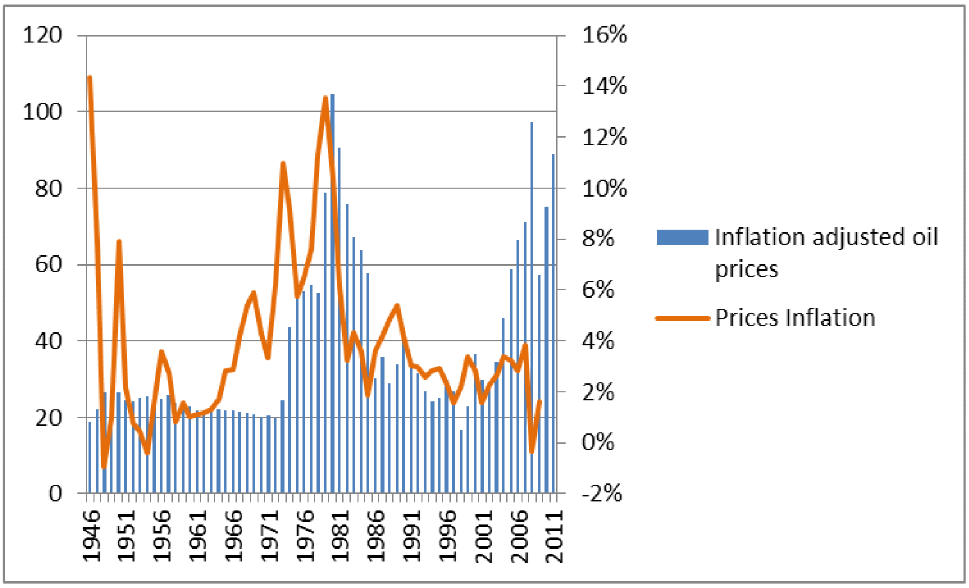

Figure 71: Relationship between oil prices and inflation in USA

Figure 71 shows that there have been relationships between oil prices and inflation, but not always. For example the recent oil spike over the last 5 years corresponded to inflation levels at historically low levels.

Example 2 and 3: low economic growth: effects on inflation

Returning to example 2 in figure 72, we can see in a long period of low growth this also corresponds to low wage growth, though not necessarily low prices inflation (the hike in inflation at the end of the 18th century was probably a result of the Napoleonic war).

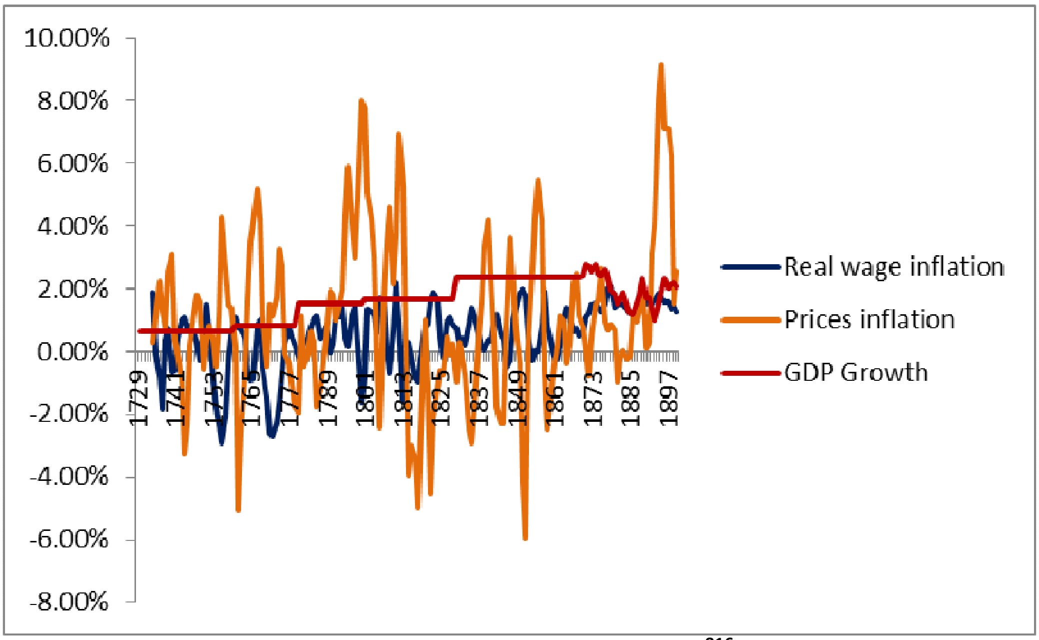

Figure 72: Pre and post industrial UK inflation and wage growth[816]

In the Japanese example (figure 73), both prices and wage inflation reduce to practically nothing as GDP growth declines.

[816] Note inflation figures are rolling 10 year averages to reduce volatility

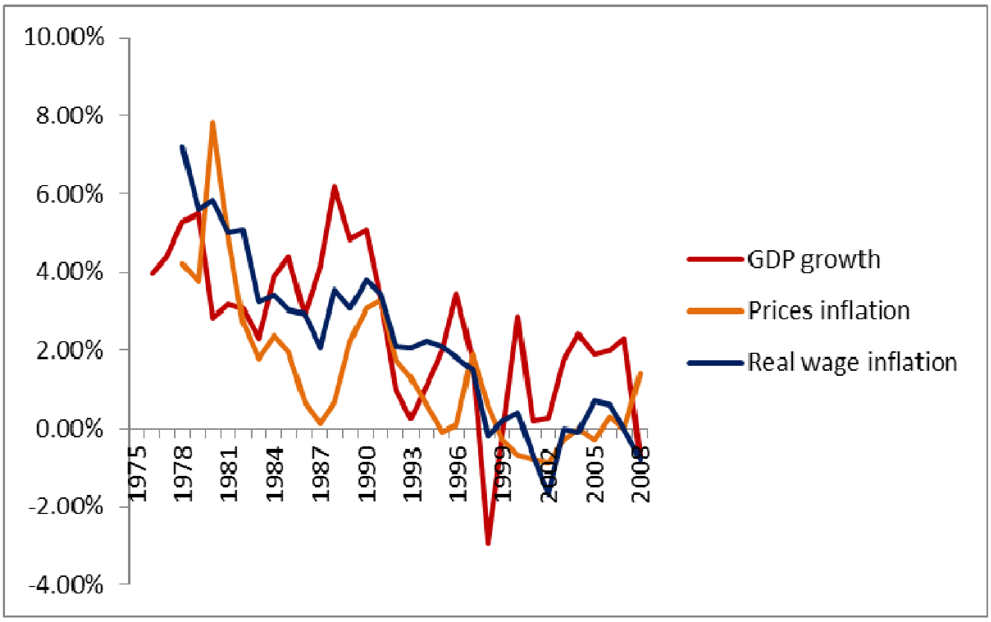

Figure 73: Inflation rates during Japanese "lost decade"

The second world war example is shown in figure 74. This shows that inflation spiraled during the war, however initially real wages stagnated or declined but then increased towards the end of the war and after during the period of re-building.

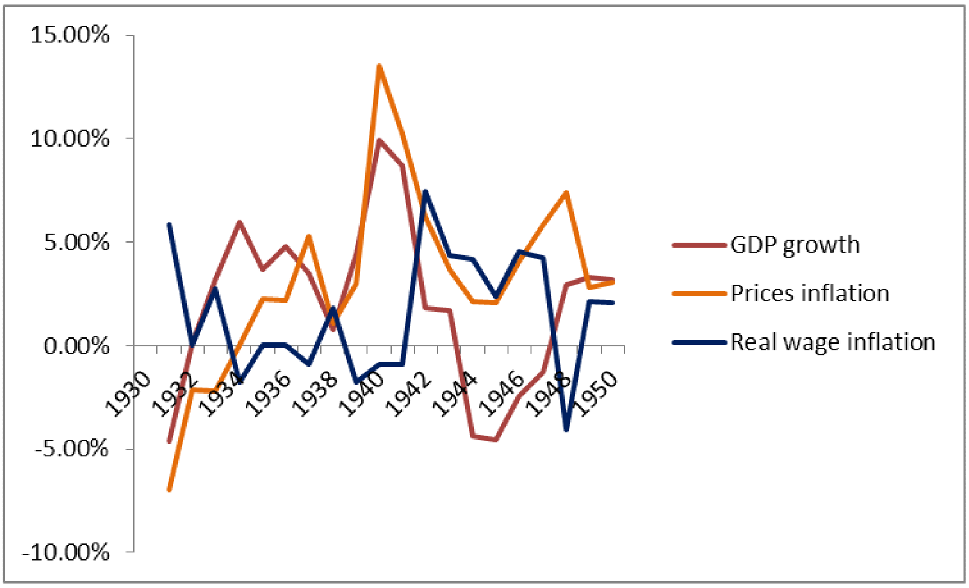

Figure 74: World War II inflation experience

Conclusions on inflation:

- Periods of low growth tend to correspond to periods of low real wage growth.
- Commodity price shocks can cause inflation, but this is not necessarily a given, it depends on the circumstances that prevail before the shock and the reaction of policymakers to the shock.
- Wages can be suppressed in times of national crisis (eg war).

7.1.3 Demographic assumptions[817]

The mortality rate at a given age is the probability that someone will die at that age. If mortality rates reduce, this will increase the life expectancy of a member of a pension scheme and hence the cost of a pension, and it will also affect life insurance calculations. Life expectancy has generally increased over time since the industrial revolution in developed countries (see figure 76), and more recently in many developing countries. Life expectancy generally increases with increasing prosperity (see figure 76), but more specifically through healthier diets, improved education (especially female), reduction in "bads" such as smoking and drinking, improved medical technology and healthcare access and with improved social security nets in general.

Morbidity is important as many pension schemes have ill-health retirement provisions, and affects the cost of health care insurance provision. Morbidity is affected by many of the same factors as mortality, but social factors also play a part; how does society and hence how do contracts define illness (this is obviously not an issue with mortality), the level of palliative care and the kind of jobs that people do (for example an injury that made you unable to work as a fireman may not affect you working as an actuary).

Possible impact of resource constraints

Life expectancies have been steadily increasing in developed countries since the industrial revolution, and more recently in developing countries. This chapter is looking at the life expectancy of a specific group of people; namely beneficiaries of a UK long-term financial product such as a pension scheme. This group is by definition select, i.e. they live in the UK which has a temperate climate and they are likely to be relatively affluent within the UK, and possibly have other benefits such as health insurance. The mortality and morbidity trends of this group will diverge significantly from that of the population as a whole (both global and UK specific).

Resource constraints could impact mortality trends in a number of ways which could be categorised as follows:

1. Impact of climate change: Climate change is predicted to increase the incidence of certain diseases (especially vector borne ones), cause increased pollution levels and increase the incidence of premature deaths from heat-waves. This is particularly relevant to pension schemes, as it is often vulnerable people such as the elderly who are killed by heat waves. Conversely a warmer UK will mean less cold winters and diseases such as influenza, which are big killers of the elderly (although there is a possibility of a cooler UK due to reduced thermohaline circulation)[818].
2. Reduced economic growth caused by resource constraints: if a country's growth rates decline, then it will have to deploy a higher proportion of wealth to servicing debt and on a social safety net, so it will have less resources to devote to health care. There will

[817] The impact of the aging population in developed countries (and in the future in some emerging economies) has been ignored in this section as it has been dealt with extensively elsewhere
[818] Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S. Kovats, B. Revich and A. Woodward (2007) *Human health. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds.,* Cambridge University Press, Cambridge, UK, 391-431.
Frum, David (2000). *How We Got Here: The '70s*. New York: Basic Books. p. 318. ISBN 978-0-465-04195-4.

be fewer jobs and hence higher social deprivation, and possibly higher inequality, which all contribute to lower life expectancy.

3. Lack of access to resources: It is possible that certain crucial elements, such as rare earth metals, may become unavailable and worsening international security situation could lead to disruption in medical supply chains. In extremis food supplies could be disrupted.
4. Change in societies' priorities: Faced with physical resource limits, climate change and international security issues, the economy as a whole will have to devote more (economic) resources to securing (physical) resources, adaptation to climate change and defence which could lead to less investment in healthcare.

Example: economic growth and life expectancy

Figure 75 shows us an example of where a country's GDP dropped – this was in the time of the Soviet Union breaking up in the late 1980s and early 1990s. This caused a great deal of social disruption including to the country's social safety net. The result was a significant drop in life expectancies, which for males (at birth) dropped from a peak of 64 to a low of 58.

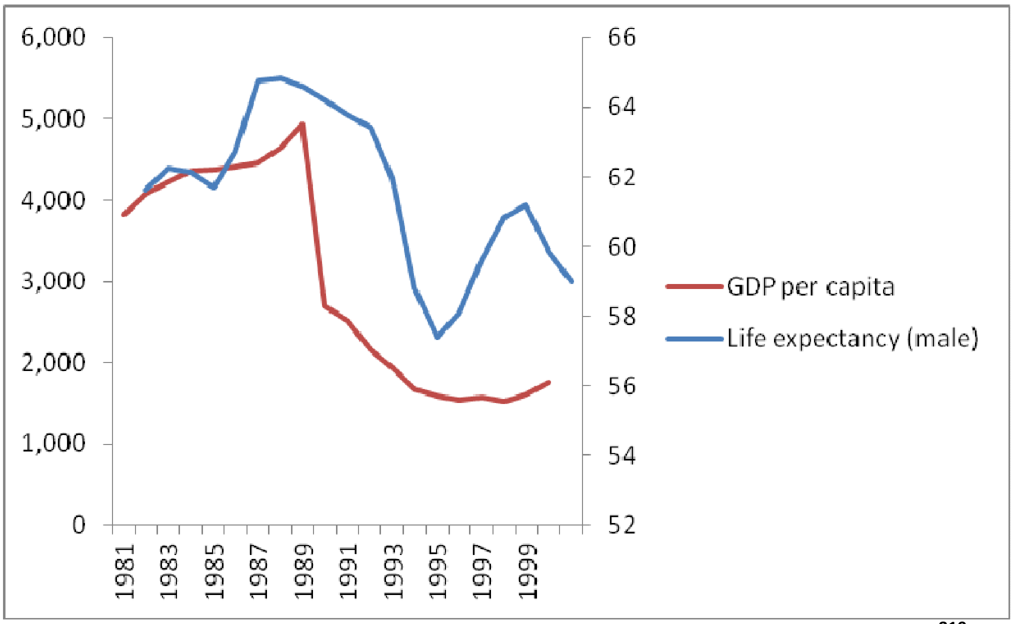

Figure 75: Life expectancy and GDP before and after the fall of the Soviet Union[819]

However, this must be contrasted with the long experience in developed countries, which has shown steady increase of life expectancies. Figure 76 shows the US experience from 1850 to the present day. Life expectancy has steadily increased in line with the growth of the economy, although the improvement has tailed off over the last 30 to 40 years.

[819] Data from UN stats division and http://dmo.econ.msu.ru/demogrus/

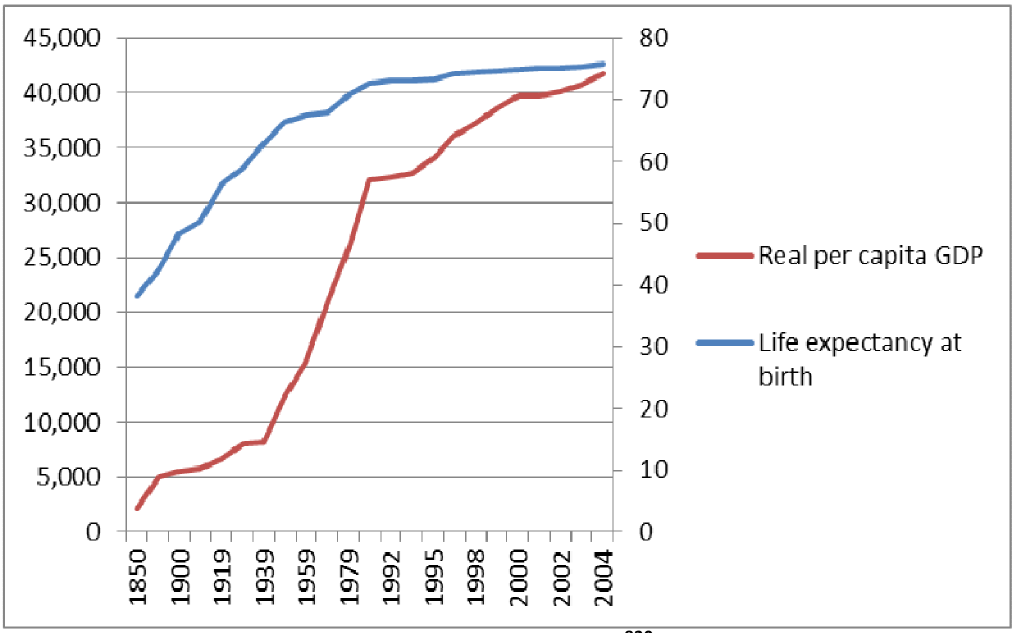

Figure 76: Historic Life expectancies and GDP in USA[820]

Conclusions on demographics:

- Developed country life expectancies have improved with time
- Periods of social and economic trauma could lead to declines in life expectancy
- Beneficiaries of long term financial products such as pensions are a select group who may be insulated from the worsening mortality of the rest of the population

7.2 Developing an actuarial model incorporating resource constraints

In this section, an actuarial model has been developed to demonstrate the effects of resource constraints which limit economic growth on a savings vehicle. A description of the models can be found in Box 7.1.

A model of two different types of scheme has been run: a simplified defined contribution scheme, and a simplified defined benefit scheme, of which there are two versions: a contribution rate increasing at a fixed rate, and with an adjusting contribution rate. These models have been chosen because they reflect current practices and each model isolates a key variable in a pension system: namely the impact on the level of pension paid out, the assets of the scheme and the cost of the scheme.

The pension system modelled could be seen as either a private or public sector system. Of great relevance to the latter, but also possibly to the former, is the ability of the sponsor (the employer or government) to stay solvent and maintain contributions. The sponsor would be subject to the same economic pressures as the economy as a whole and may therefore be vulnerable in some scenarios – which would be an important consideration for a real-life analysis. The pensions sector has and will be subject to legislator changes, which will also affect the cost of provision – these have been ignored.

The model used in this report implicitly assumes that either the sponsor remains solvent, or someone else (for example a government, or pension insurance arrangement such as the Pension Protection Fund) faces the resultant costs from the pension scheme, even if these

[820] Data source: http://www.infoplease.com/ipa/A0005140.html

may be unaffordable for the sponsor. This allows us to analyse the cost and outcomes of a pension system.

These models were run using the 4 scenarios developed in the previous chapter. To explore the pessimistic and optimistic assumptions in the scenarios each was broken down into two possible futures (therefore, 8 futures are explored). These 8 scenarios were then compared to a baseline “no constraints” scenario – this assumes the future is broadly in line with the past. No probabilities are attached to the likelihood of any of these scenarios, and no view is taken as to which is the most likely; they are “what-if” scenarios which attempt to translate the scenarios built up in the rest of this report into an actuarial basis.

These scenarios do not reflect a worst case scenario. Were the global economy to go into long term decline; the legal basis on which financial products sit could conceivably be undermined, and the sponsor employer may no longer exist to pay contributions, the financial markets may also cease to exist, at least in their current form, and hence the projection would become meaningless.

Bearing in mind therefore that the scenarios presented here should be considered as being on the mild end of the scale, and also that the savings vehicles are simplifications of reality and are ignoring existing and future legislation, initial conclusions from the model outputs are:

1. The more extreme scenarios modelled represent financial disaster; the assets of pension schemes will effectively be wiped out and pensions will be reduced to negligible levels.
2. If resource constraints impact but not to such a severe extent, there still could be considerable impact on a financial vehicle. The different reaction of governments, regulators and financial agents can produce a spectrum of impacts the outcome of which will have an effect on savings vehicles.
3. Currently actuarial models are effectively discounting to zero the probability of economic growth being limited by resource constraints. If resource constraints are significant, this means that current models will persistently understate the value of liabilities.

Box 7.1 Characteristics of simple savings model

Defined benefit system	Defined contribution system
The model represents a simplified version of an occupational defined benefit pension scheme with the following characteristics: Beneficiaries join at age 25 and work for 40 years They receive a pension at age 65 payable for life of 50% of their final salary. The pension increases in payment in line with inflation Members of the scheme contribute at 5% of salary *Model version 1:* The sponsor or employer of the scheme contributes at 7.5% of salary initially increasing at 0.15% per annum. *Model version 2:* The sponsor increases contributions if the scheme is in deficit. ***Impacts of resource constraints will increase the cost to the sponsor of this system and the asset levels of the system***	The model represents a simplified version of a defined contribution pension scheme with the following characteristics: Beneficiaries join at age 25 and work for 40 years Contributions of 12.5% of salary are paid (7.5% by employer, 5% by member) into the scheme. These accumulate until retirement, and are then converted into a pension through the purchase of an annuity. The pension increases in payment in line with inflation ***Impacts of resource constraints will reduce the level of benefits paid out.***

Though the model is much simpler than anything in reality, it does share some of the characteristics of many pension schemes, namely contributions are paid through an employee's working life, and they then receive a pension related to salary. We have modelled a pension fund rather than, for example, a life or non-life fund, as pensions contracts are generally long term and therefore the effects of the World model become the most apparent.

The projection period of the model is over a 100 year period, but the output displayed below is 60 years as this gives the best illustration of the trends. The model uses 2012 as a starting date. However, this starting date should be viewed as nominal, the model is investigating what might happen to the pension fund modelled under the economic and demographic scenarios discussed. If this were to occur in the future, it will not necessarily occur in the period suggested – for example Randers (2012) suggest that most of the damage from climate change will occur after 2052.

Input scenarios

Table 7.1 describes how the scenarios developed in this paper can be thought about in actuarial terms.

Table 7.1: Actuarial implications of scenarios

Outcome	Scenario	Actuarial implications
<u>**Business as usual**</u> **Pessimistic predictions:** Long term global economic decline (based on energy availability) and local decline (based on food and water availability) **Optimistic predictions:** Slightly delayed long term global economic decline	• Prices for resources based on flows rather than stocks. • Decision making based on no limits to resources. • Price signals changes come too late: resource prices continue to be volatile. • When resource limits are approached there are abrupt and discontinuous changes leading to local, national or long term global economic decline	**Discount rates:** Assumed returns should be low in both matching and budgeting calculations. Backward looking models may overestimate the returns based on market yields compared to what might actually happen. **Investment return:** starts off as BAU, then reduced due to volatility of resource price, before large reduction due to shock. Post shock returns are very low and suffer from series of aftershocks. **Prices inflation:** steadily increases as governments fail to control **Wages inflation:** increase initially then decline as the economy becomes non-viable **Mortality:** gradual increase in life expectancy with BAU followed by fall

Outcome	Scenario	Actuarial implications
<u>Price driven change</u> **Pessimistic predictions:** Some local long term declines in developing & emerging countries but major global economic decline averted **Optimistic predictions:** Major global economic decline averted and fewer regions impacted by local declines	• Governments have a low sensitivity to resource limitations • markets have a long term outlook and price signals drive changes • Innovation within business is driven by investment into alternative technologies • No regulation is put in place to manage availability of resources • only those that can afford to pay gain access to those limited resources. • Energy prices and resource prices continue to rise until new technologies come online. • Technological or service solutions are found to all resource limitations. • There is an increasingly inequitable distribution of resources	**Discount rates:** Matching rate might increase due to increased uncertainty. Budgeting rate should fall as much outperformance is expected from emerging economies, but backward looking models may not predict this. **Investment return:** reduced due to large proportion of assets in and affected by emerging economies. **Prices inflation:** many goods will become increasingly expensive or unavailable. Government tempted not to control money supply and hence cause inflation. **Wages inflation:** this could go either way, as we need to pay more for resources relative wages may fall. Alternatively, less competition from low paid foreign workers may drive up wages. Increased immigration pressure may dampen wage growth, but to a lesser extent. **Mortality:** gradual increase in line with BAU but will stabilise as the local economy does not decline too severely.

Outcome	Scenario	Actuarial implications
<u>Regulation driven change</u> **Pessimistic predictions:** Some local declines in all countries and long term global economic decline follows due to market failures **Optimistic predictions:** Fewer local declines but global economic decline follows - delayed from the pessimistic prediction	• Governments operate on a long term basis and regulate the stock of resources rather than flows. • Markets remain short term in focus and price resources based on flows. • Change is driven through increases in taxes and direct regulation. • Innovation is not as effective as could be with sporadic changes and highly volatile energy prices. • Feedback from market change to policy development is not effective and often policy fails to deliver. Certain resources are managed while others are over-exploited and the impact is uncertain with some key services being ineffective.	**Discount rates:** Assumed returns should be low in both matching and budgeting calculations. Governments may attempt to supress yields and then declines caused by bad economy. Backward looking models may not predict this. **Investment return:** Regulation may supress returns and then they will fall due to decline in economy. **Prices inflation:** may increase as government uses inflation as a policy tool **Wages inflation:** these may be capped as well, although could increase if skilled labour is scarce and in demand **Mortality:** gradual increase in life expectancy with BAU followed by rapid fall

Outcome	Scenario	Actuarial implications
<u>**Consensus driven change**</u> **Pessimistic predictions:** Some local declines however global economy stabilises based on new technology deployment **Optimistic predictions:** Fewer local declines and global economy stabilises	• Governments and market operate on long term basis, pricing and regulating resource stock rather than flows. • Government and markets work in harmony to develop policy and frameworks that enable and build on market innovation and mechanisms. • Prices are stable and reflect long term changes in resources availability making facilitating investment into innovation • Government regulation supports the deployment of alternative technologies to ease transition. • The transition from certain resources is managed so that prices for services are equitably to ensure widespread access and long term investments based on predictable returns.	**Discount rates:** Assumptions remain similar to without constraints **Investment return:** Initially returns may be low as some asset classes perform badly and government intervention may supress yields. However, then may grow in the long term. **Prices inflation:** initial increase pressure but ultimately economy is more resilient so should be brought under control **Wages inflation:** This may show steady increase as labour becomes more productive **Mortality:** gradual increase in line with BAU; technology should aid increases in life expectancy.

Setting assumptions
To apply a scenario to the actuarial model, a set of assumptions has to be formulated. Traditionally when setting assumptions, there is an implicit assumption that conditions in the future will resemble conditions in the past, so a variety of techniques are used to establish a justifiable basis.

For resource constrained scenarios, the future will necessarily look different from the past, so there is no basis for establishing what the individual assumptions might be. The discussion above gives an indication of which direction those assumptions might be, but does not really establish their magnitude. However, the purpose of building up scenarios is to show what might happen, and therefore the table below proposes sets of assumptions which might reasonably conform to the scenarios described above.

It is important to note that no judgment has been made on the likelihood, either relative or absolute, of each scenario, they are simply stated as “what-if” scenarios; the given scenario is simply used to model an outcome. The scenarios are presented in Table 7.2.

As outlined above there are nine scenarios as firstly we have a base case scenario where there are no implications of resource constraints for comparison purposes – this assumes the future is broadly in line with the past. The other scenarios are to be compared to this baseline. Each of the scenarios corresponds to one of the scenarios developed in the previous chapter (bearing in mind that there is an “optimistic” and “pessimistic” category within each scenario). So for example, “Islands of stability (B2)” corresponds to “Business as usual” optimistic scenario.

Table 7.2: actuarial scenarios used in modelling

<table>
<tr><td colspan="4"><u>No resource constraints basis (N):</u>
Under this scenario resources to do not constrain growth; i.e. this is a baseline set of assumptions intended to be a proxy for conditions of extrapolated growth of a feasible magnitude in the absence of resource limitation
Discount rate: 3%
Investment return: 3%
Wage inflation: 2%
Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase by 1 year every 5 years</td></tr>
<tr><td colspan="2"><u>Business as usual (B)</u></td><td colspan="2"><u>Regulation driven change (R)</u></td></tr>
<tr>
<td>Severe Decline (Scenario B1): Resource constraints and climate change set off a breakdown in society and international security which leads to collapse severedecline of the economy
Discount rate[821]: 3%
Investment return: 3% reducing to 0% with severe periodic negative shocks
Wage inflation: 2% reducing to 0%
Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N, then remain static with periodic negative shocks</td>
<td>Islands of stability (B2): general economic decline but some areas survive relatively intact, including where the modeled pension system operates, hence wages increases and mortality stabilizes for pension scheme members
Discount rate: 3%
Investment return: 3% reducing to 0% with periodic negative shocks
Wage inflation: 2%
Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N, then remain static</td>
<td>Financial repression (R1): government unsuccessfully attempts to stave off general economic decline with directed investment through suppression of returns
Discount rate: 2%
Investment return: 2% reducing to 0% with periodic negative shocks (delayed from B1)
Wage inflation: 2% reducing to 0%
Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N, then remain static with periodic negative shocks</td>
<td>Partial decline (R2): government manages to partially avoid severe economic decline wages continue to increase and mortality stabilises for pension scheme members
Discount rate: 2%
Investment return: 2% reducing to 0% with periodic negative shocks (delayed from B1)
Wage inflation: 2%
Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N, then remain static</td>
</tr>
</table>

821 The discount rate and investment return assumption are differentiated here: the discount rate is what actuaries are using in their basis but the investment return is what happens in reality.

Price driven change (P)		Consensus driven change (C)	
Wage stagnation (P1): *many local regions decline but global decline averted, but damage to economy halts real wage growth* Discount rate: 3% Investment return: 3% reducing to 1.5% with periodic negative shocks Wage inflation: 2% reducing to 0% Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N, then remain static	***Labour shortage (P2):*** *fewer local declines and actuaries anticipate decline. Higher wage growth due to shortage of skilled labour* Discount rate: 3% reducing to 2% Investment return: 3% reducing to 2% Wage inflation: 2% increasing to 3% Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N, then remain static	***Partially adaptation (C1):*** *some local decline but most avoided, with relatively high returns due to increased investment requirements* Discount rate: 3% Investment return: 3% reducing to 2% Wage inflation: 2% Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N	***Green growth (C2):*** *fewer local declines and continued growth, which leads to high investment returns and wage growth due to advances in new economy* Discount rate: 3% Investment return: 2% increasing to 3% Wage inflation: 2% increasing to 3% Mortality: PMA92/PFA92 (Medium cohort 2005 projections): life expectancy to increase in line with N

PMA92/PFA92 refer to standard life tables outlining mortality rates for males (PMA92) and females (PFA92).

Results of model
The model described in box 7.1 was run as follows: firstly a defined contribution scheme, secondly a "defined benefit" scheme where the contribution rate is fixed, and finally a defined benefit scheme where the sponsor adjusts contributions when the scheme runs into deficit. The purpose of these three runs is to focus on key outcomes, namely level of benefits, funding level and cost.

Defined contribution schemes
In this model the sponsor (employer) makes contributions into the scheme at 7.5% of salary (increasing by 0.15% per annum to allow for improving mortality) and the member contributes at 5% of salary. This fund is accumulated for each member and used to purchase an annuity when they retire at prevailing interest rates.

Figure 77 shows a comparison of replacement ratios for the different scenarios (the replacement rate being the initial pension paid on average divided by the salary prior to retirement).

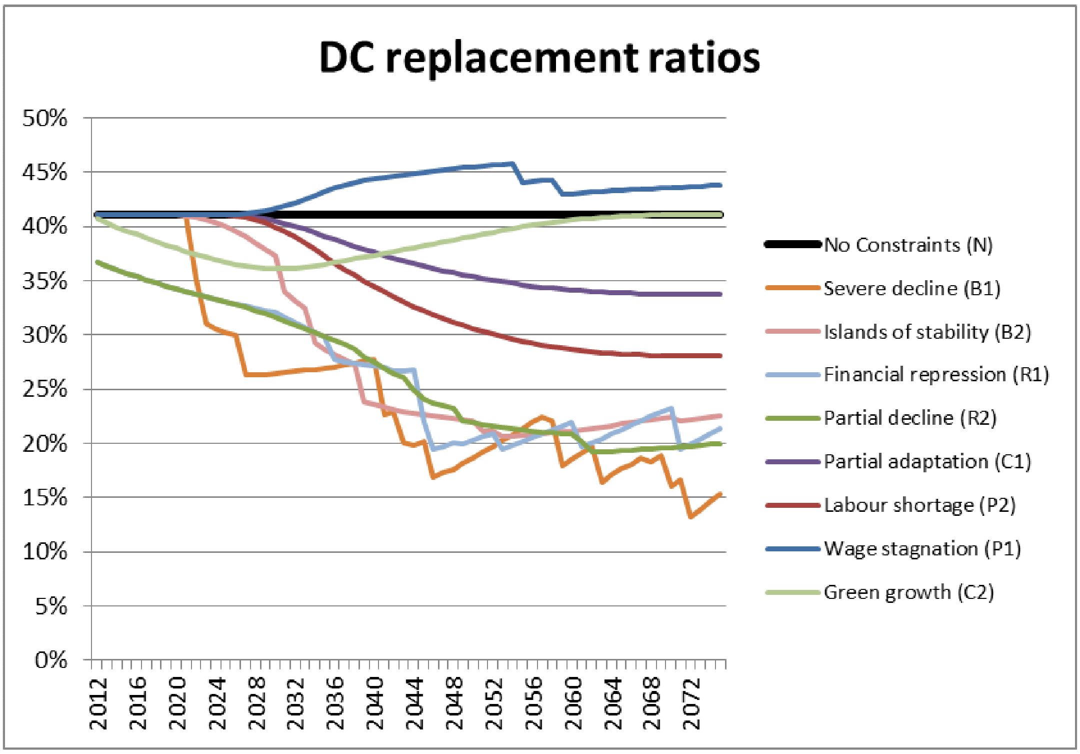

Figure 77: Replacement ratios: all scenarios

Figure 77 shows that the replacement ratio under the no constraints scenario is steady at 40%. Under wage stagnation scenario, the replacement rate is approximately the same, or even a little higher. This is because the wage growth under this scenario reduces to zero, whereas the assets still give positive returns, hence the pension is relatively high compared to the returns under this scenario. All other scenarios give rise to far worse outcomes as replacement rates decline with time, with a worst case of severe decline where replacement rates are around 15% (this is where the wages of the skilled workers who are members of the scheme continue to increase but investment returns are poor).

The results of this model are driven by two major factors. First of all whether the wages of scheme beneficiaries continue to rise, this is shown in figure 78. In this figure and following ones, a few of the scenarios are chosen which best illustrate the points being discussed.

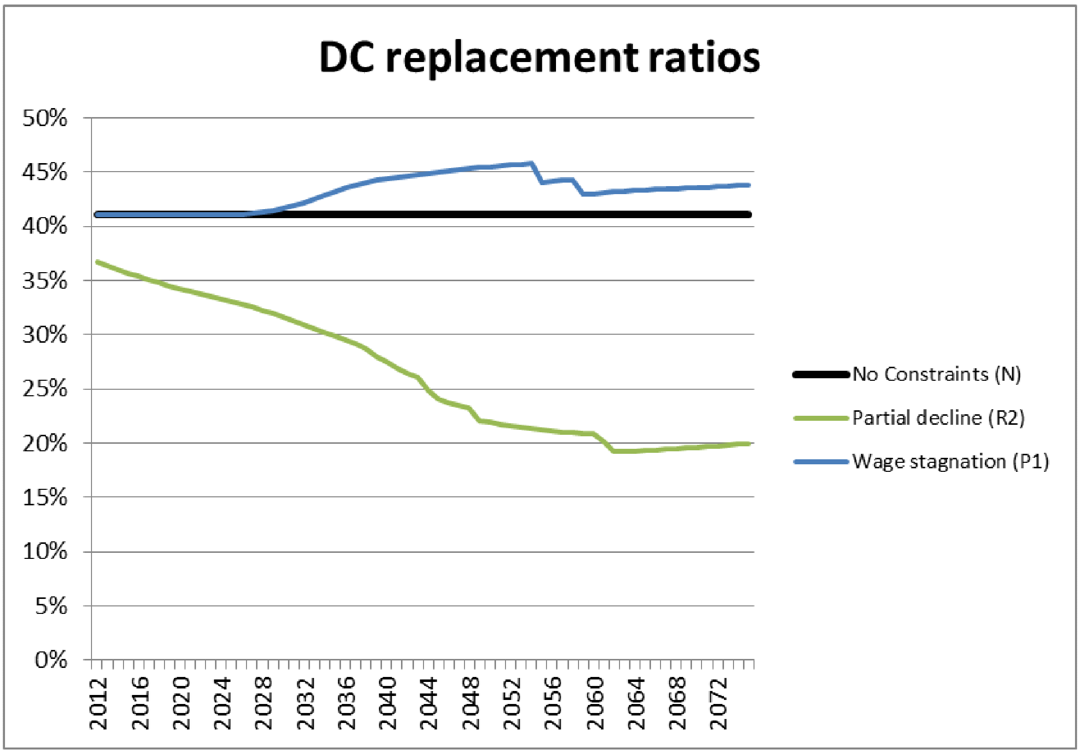

Figure 78: Replacement ratios: comparison of partial decline and wage stagnation

Under the wage stagnation scenario there is no more real wage growth, so investment returns keep the replacement ratio high. However, under the partial decline scenario wages increase more than investment returns leading to declining replacement ratios. This does not mean resultant pensions are any higher in the former scenario, simply that salaries before retirement are lower.

The other major difference is investment returns as can be seen from figure 79. In the partial adaptation, investment returns hold up whereas in the islands of stability scenario they do not leading to very low replacement ratios.

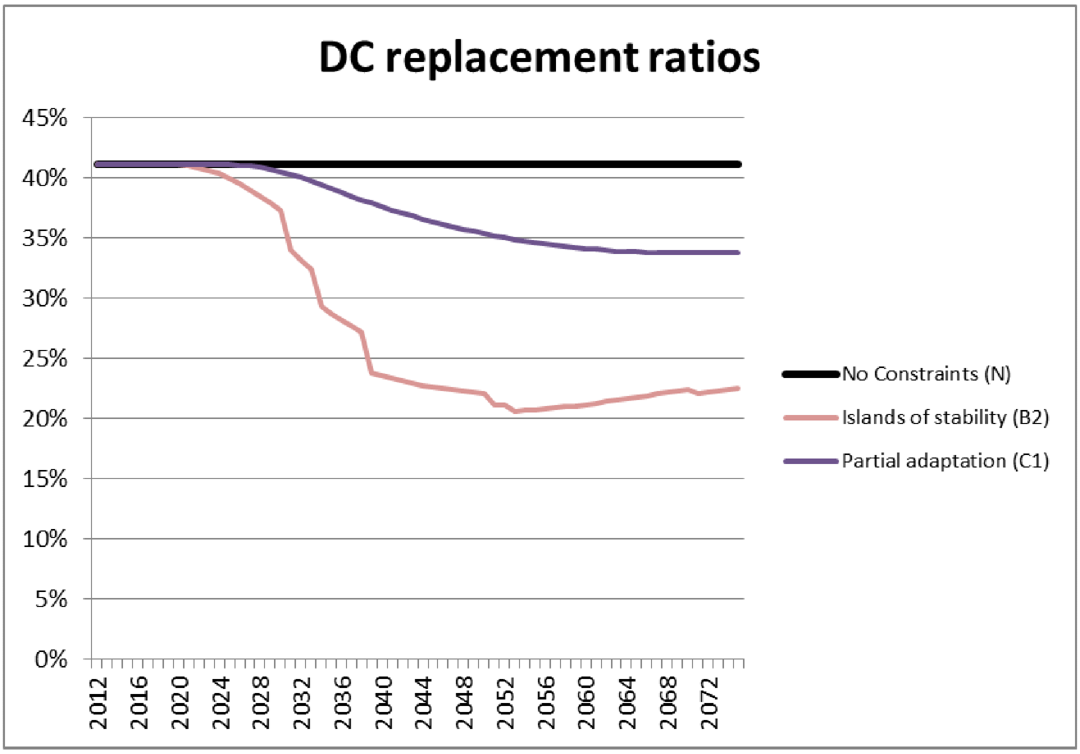

Figure 79: Replacement ratios: comparison of islands of stability and partially adaptation scenarios

Fixed defined benefit scheme

In this version of the model the sponsor (employer) makes contributions into the scheme at 7.5% of salary (increasing by 0.15% per annum to allow for improving mortality) and the member contributes at 5% of salary.

Figure 80 shows the output of the base case scenario where there are no resource constraints.

In this scenario, the contributions initially exceed the pension payments, but the situation is soon reversed. However, the assets of the scheme continue to build up through time, as the excess payments are somewhat offset by the interest on the assets.

This scenario is in contrast to figure 81, which represents the extreme case of a severe economic decline.

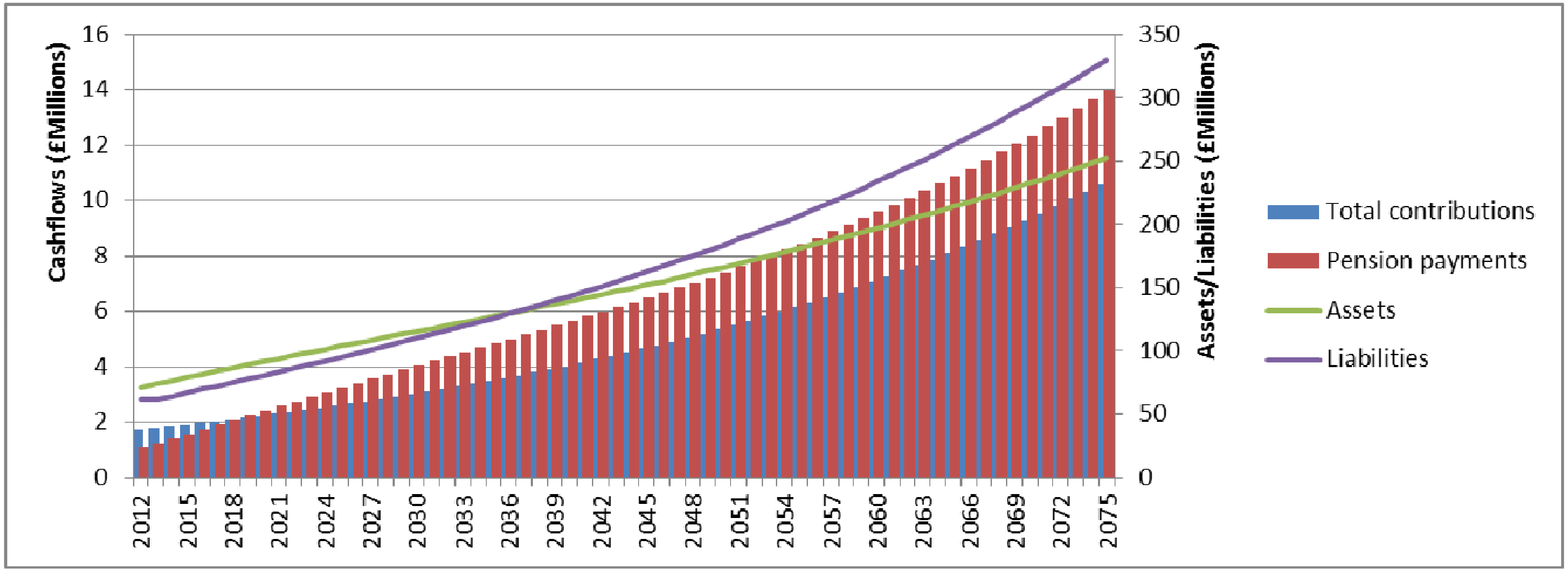

Figure 80: Defined benefit: No resource constraint scenario

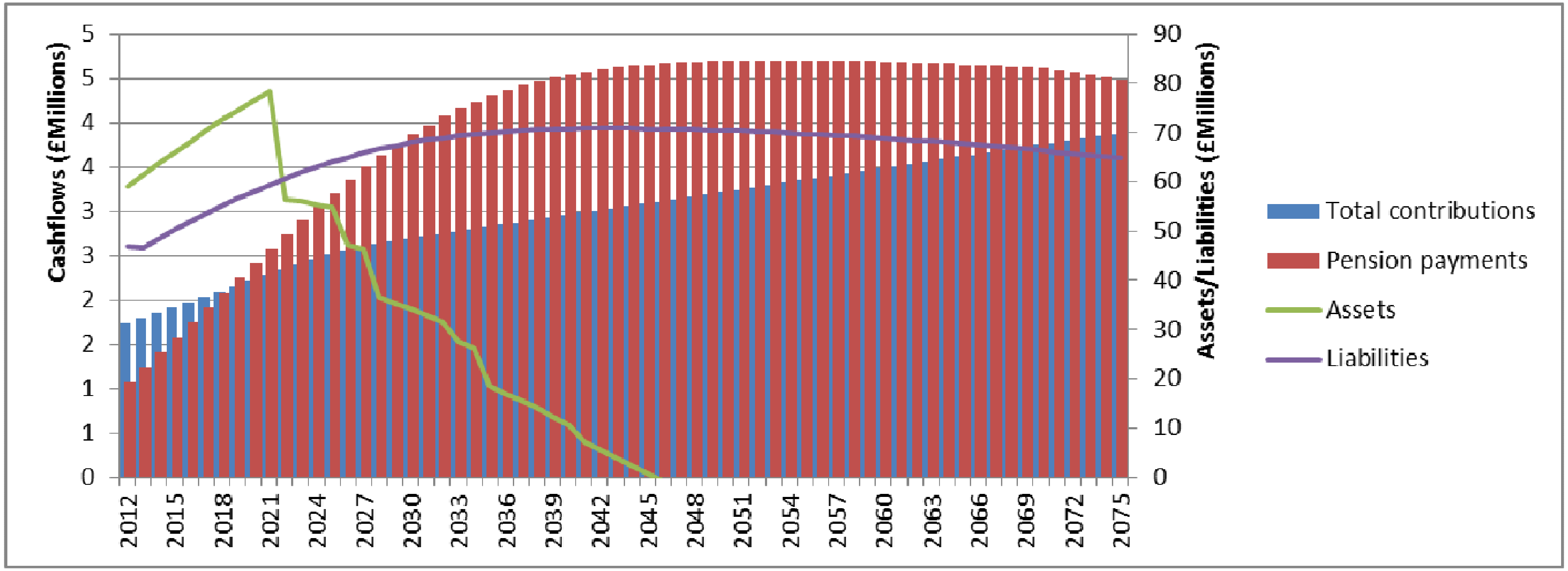

Figure 81: Defined benefit scheme: Severe economic decline

In this scenario, the pension payments rapidly exceed the contributions. The assets collapse as a result of this but mainly due to sharp declines in financial markets.

The model was run with all of the scenarios described in Table 7.2. The projected assets of the scheme are compared in figure 82.

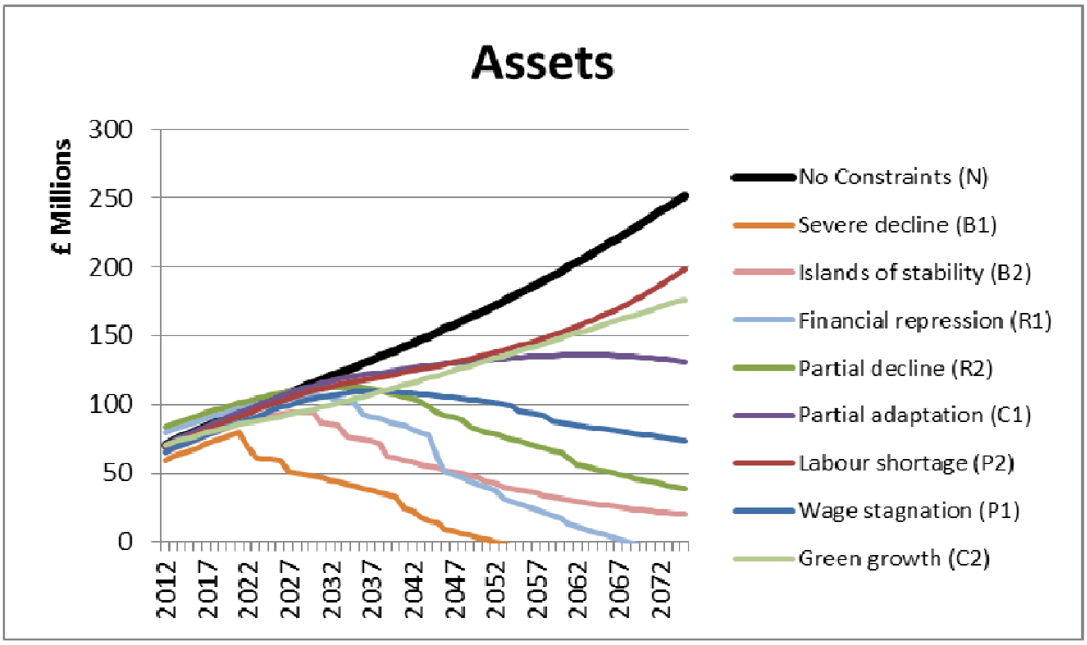

Figure 82: Defined benefit scheme asset projections: all scenarios

Under the No constraints scenario the assets of the scheme increase from £70million to around £250million by 2075. In sharp contrast, the worst case scenario is global economic decline where assets are exhausted by 2052. All of the other scenarios lie in between these extremes.

However even between these two extremes there is still much variation, with financial repression where assets decline to around zero solely as a result of the limitations to growth as modelled, and in the absence of other detrimental influences (such as those experienced over the last 15 years in some western countries), and labour shortage with assets increasing to around £200m (figure 83). The reason for the regulatory-driven scenario performing badly is that the returns are constrained in this case as capital is compulsorily transferred to resource substitute sectors in addition to negative asset shocks. The price and consensus driven change scenarios are generally more favourable as investment returns are good as substitutes for resources are successfully deployed through increased investment.

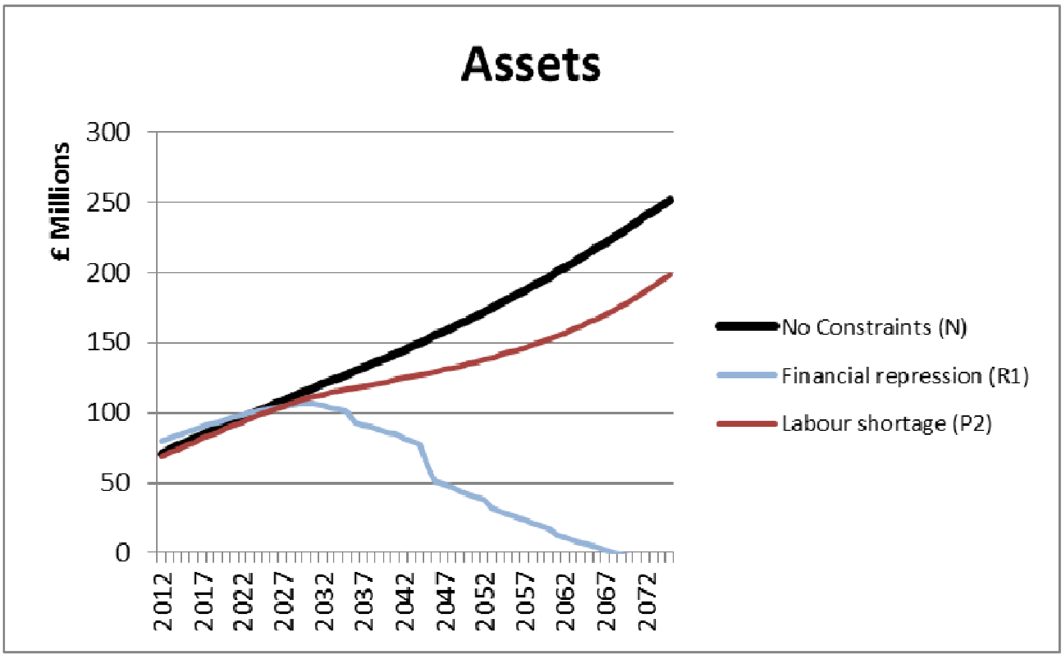

Figure 83: Defined benefit scheme asset projections: financial repression compared to labour shortage scenarios

Adjusting defined benefit scheme

The second version of the define benefit model the sponsor (employer) makes contributions into the scheme at 7.5% of salary (increasing by 0.15% per annum to allow for improving mortality) and the member contributes at 5% of salary. However, in addition, if in any given year the liabilities of the scheme are greater than the assets, the sponsor makes an additional contribution[822]. This model slightly more realistically replicates the behaviour of a real pension scheme.

Figure 84 shows the output of the base case scenario where there are no resource constraints.

In this scenario, the contributions exceed the pension payments and the liabilities continually exceed the assets but at a relatively stable rate. The four variables approximately increase in parallel.

This scenario is in contrast to figure 85, which represents the financial repression scenario, the case of regulatory driven change. In this case, the downward pressure on the assets is too great for the extra contributions to keep up, so that there is a persistent and growing deficit. This also assumes that the sponsor continues to exist to pay/increase contributions.

A key factor in this model is whether or not actuaries anticipate the change in conditions. In the financial repression scenario, actuaries use a discount rate of 2%, whereas investment returns fall. This results in liabilities always exceeding assets from 2030 and increasing contributions.

[822] The extra contribution is the liabilities less assets amortised over 15 years

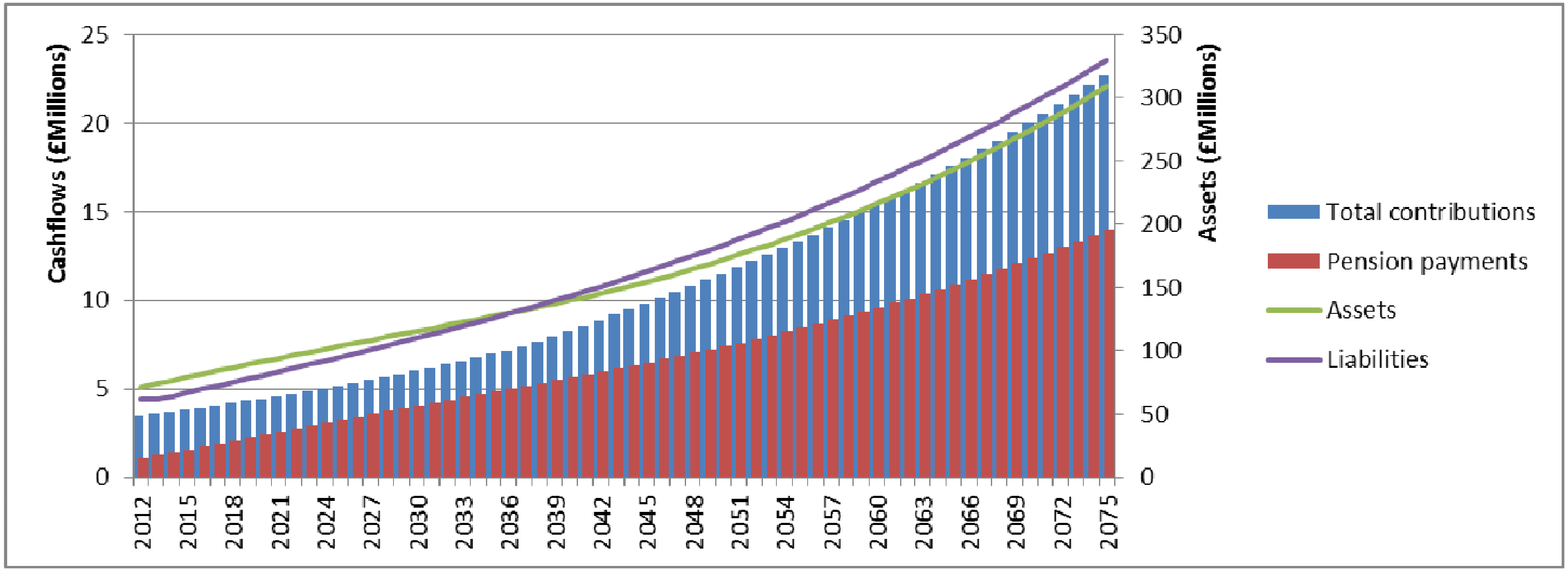

Figure 84: Adjusting defined benefit scheme scenario: No resource constraint scenario (N)

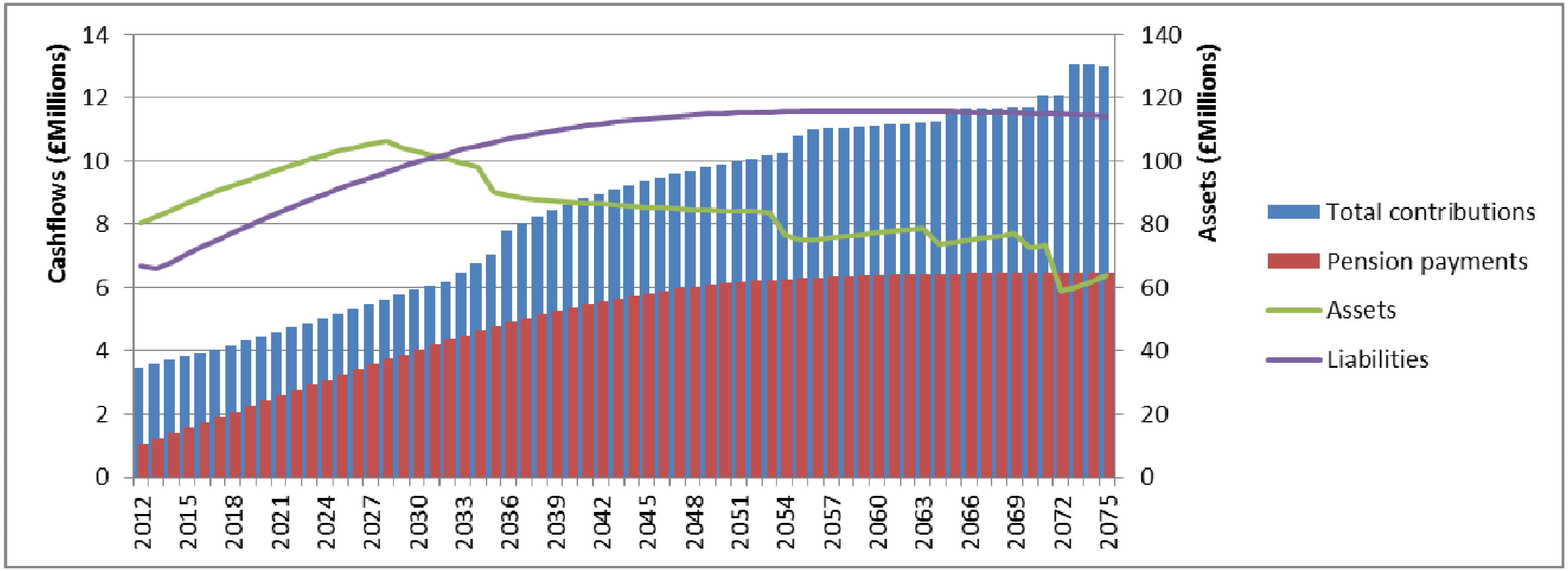

Figure 85: Adjusting defined benefit scheme: financial repression scenario (R1)

The model was run with all of the scenarios described in Table 7.2. A comparison of the assets and the costs of the scheme of all scenarios are shown in figure 86 and 87.

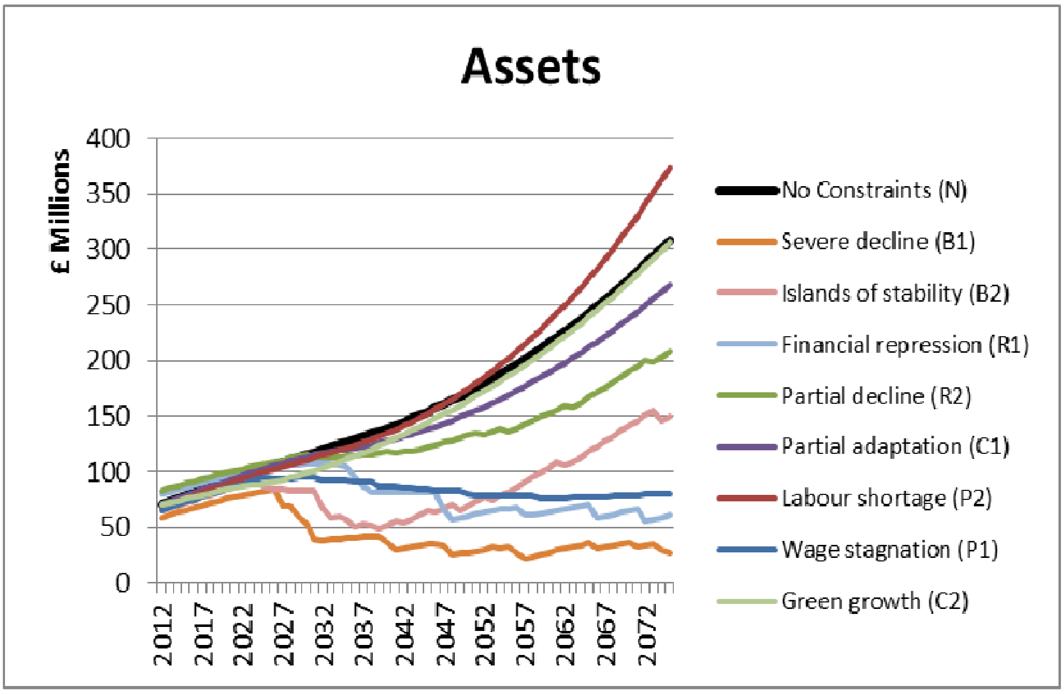

Figure 86: Adjusted Defined benefit scheme asset projections: all scenarios

The cost of the scheme under different scenarios is shown in figure 87, which is defined as the total annual contributions.

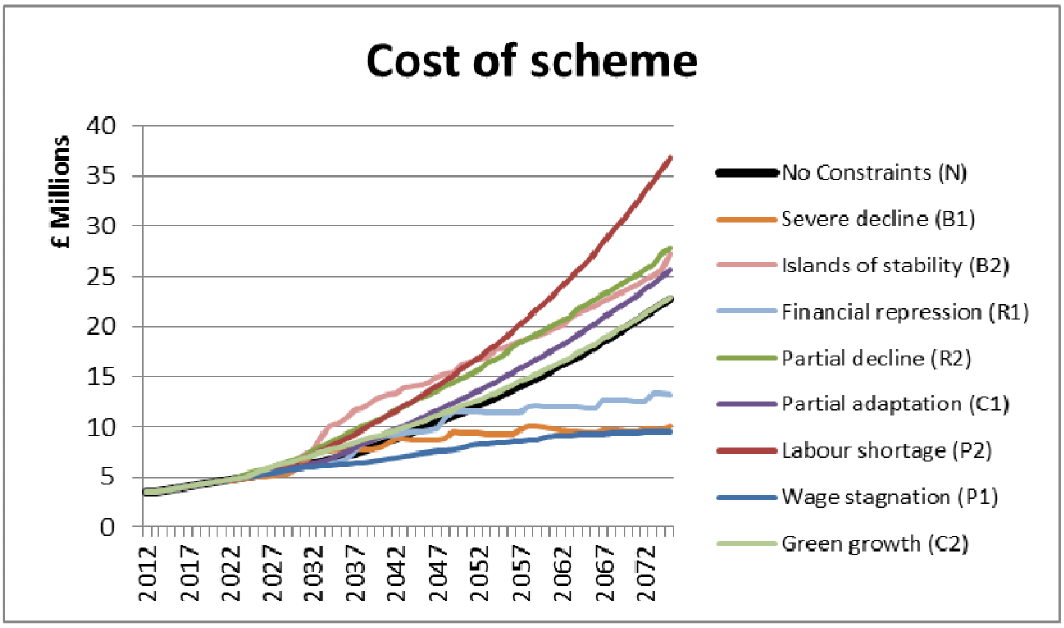

Figure 87: Adjusted Defined benefit scheme cost of scheme projections: all scenarios

Under the no constraints scenario (N) the assets of the scheme increase from £70million to around £300million by 2075. In sharp contrast, the worst case scenarios are severe decline and financial repression where assets reduce to less or a little more than £50million, though even this may not be realistic as the sponsor may no longer exist under these scenarios to pay contributions.

Labour shortage gives rise to slightly higher assets than the no constraints scenario, but all of the other scenarios lie in between these extremes. The picture from the cost of scheme (to both sponsor and member) is much more complex as the scenarios divide into two distinct groups. In the decline scenarios, the annual cost is actually lower than the base case scenario. This may be due to the lesser increase in the wages, so the contributions are lower. In the other scenarios, the cost is higher, which reflects a number of different factors.

Figures 88 and 89 contrast 2 scenarios; partial adaptation and labour shortage. The scenarios differ in 2 major ways, in the labour shortage scenario, actuaries anticipate the worsening economic situation, and real wage inflation for the pension scheme beneficiaries increase; they represent a select group of labour who are needed and highly valued in an increasingly stressed world of resource constraints and possible worsening security.

The outcome is that the cost of the scheme is higher for the labour shortage scenario, as the pension is earning the same amount but paying higher pensions (as the salaries increase by more). Similarly the asset build up is higher, but this reflects that higher contributions are paid and more assets are required to pay higher pensions (and lower returns are anticipated by actuaries).

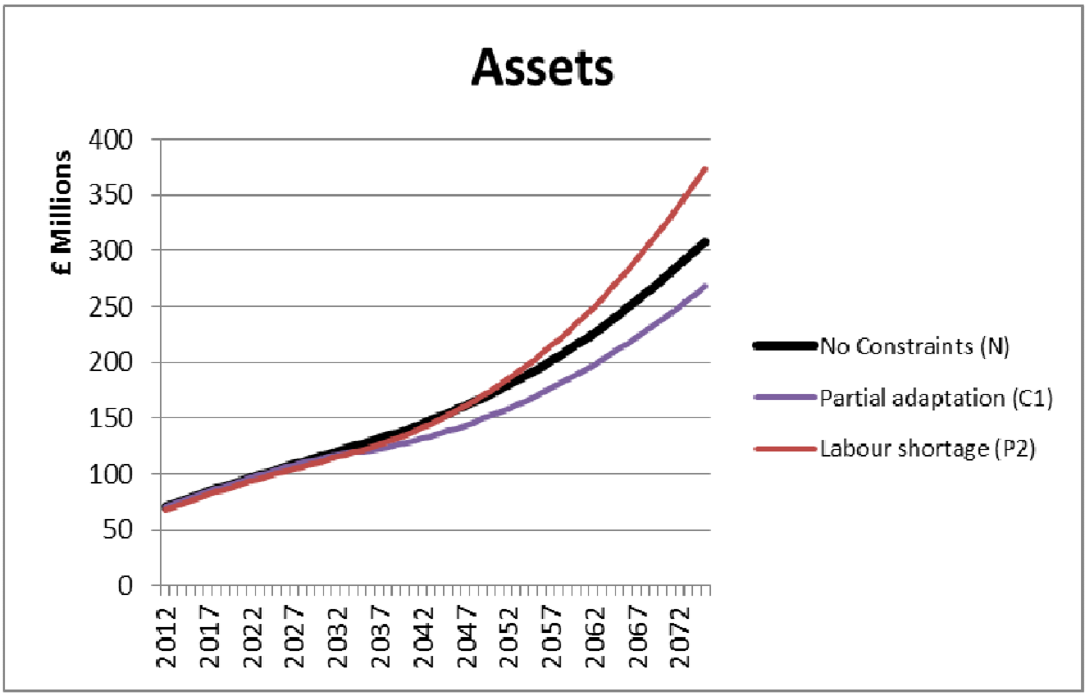

Figure 88: Adjusted Defined benefit scheme asset projections: partial adaptation and labour shortage scenarios

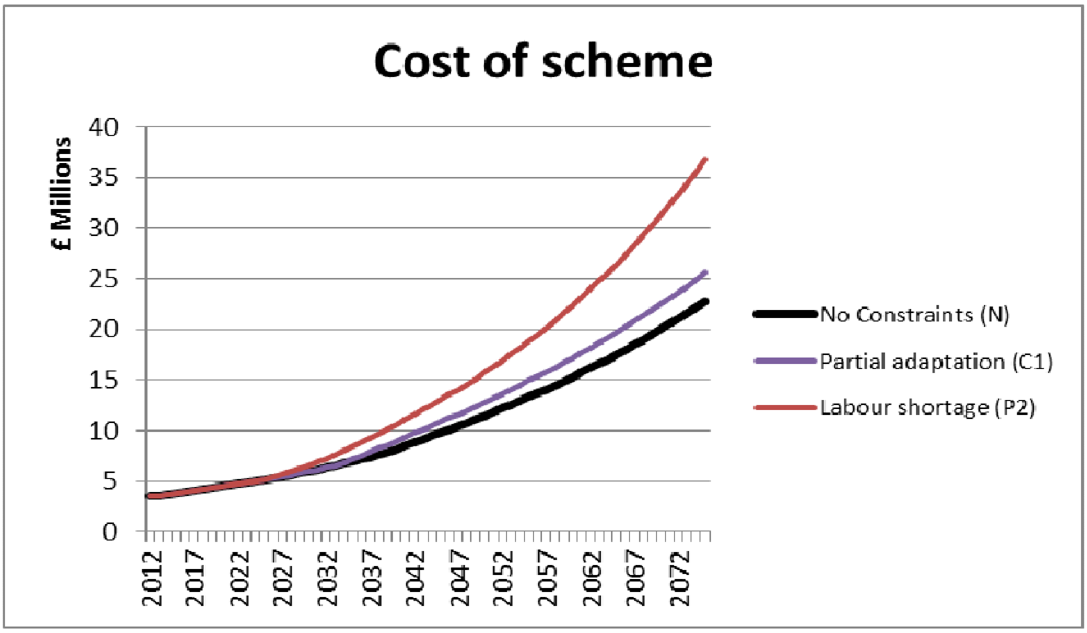

Figure 89: Adjusted Defined benefit scheme cost of scheme projections for partial adaptation and labour shortage scenarios

7.3 Implications for actuaries

The overall conclusion of the modelling exercise undertaken in this report is that if future economic growth is limited by resource constraints, then the impact on a long term savings vehicle such as a pension fund would be profound and actuarial projections are not taking this into account. Therefore, we need to question what is the likelihood of such a future. To do this, actuaries need to become conversant in a number of issues which are not within their traditional range of expertise, such as the relationship between energy and other resources and the economy and the economic impacts of climate change. The impact of resource constraints on actuarial modelling raises a number of other implications for actuaries which are described here.

Actuarial methodology

Much of the difference in outcomes of resource constraints depends upon the action or re-action of society to a real or perceived threat. The reaction depends on decisions taken about the political economy and therefore to make projections about financial outcomes requires understanding of the processes over how these decisions come about. Many of these do not just apply to resource constraint issues; areas identified as being particularly important were:

1. Money supply and inflation: short term inflation could be caused by commodity price spikes but long term inflation depends upon the money supply, and hence long term inflation levels are a political decision as this is effectively controlled by government.
2. Globalisation and international security: some countries may do better in a resource constrained world than others, but a financial vehicle in one country can currently diversify its assets into other countries. However, this has not always been the case and might not always be the case in the future. This will depend on issues such as international relations, global financial architecture and international institutions.

3. Equity and ownership: the performance of a salary linked financial vehicle depends on the relationship between investment return and salary growth. This in turn depends upon returns to capital and labour, and how the benefits of economic growth are distributed. It was discussed how in times of trauma, governments could chose to engage in financial repression, and encourage or force increased savings and investment at the expense of consumption – this often happens in times of war or following debt crises. This outcome crucially depends on the political economy within a country.

Actuarial models make extensive use made of historic data; specific emerging risks, such as resource constraints, will therefore not show up in historic data. This has been true of many risks in the past, such as asbestos and AIDS, and historic data therefore might not include specific "new" risk but will include many risks that have emerged in the past. However, a major difference between past emergent risks and resource constraints is that the latter are embedded within the fundamental structure of the economy and therefore could potentially lead to a step change in financial outcomes. The same may be true of some other new risks, for example if medical technology significantly increases life expectancy this could fundamentally undermine existing pension scheme design.

Demographic factors: the profession produces life and mortality tables which are relied upon by practicing actuaries and others. This report identifies that resource constraints could have multiple impacts which might directly or indirectly impact mortality and morbidity rates.

Professionalism issues
Client advice: actuaries advise many clients, predominantly pension funds and insurance companies, but also other institutions such as banks, corporations and governments. The actuary is typically advising on issues of risk management often over long-term time horizons. This report has shown, without commenting on the likelihood of such events, that if there are resource constraints this could have a severe potential impact on savings vehicles.

Public interest: actuaries have a core obligation to serve the public interest[823]. Many of the issues in this report are magnified or dampened by the actions of government and other financial actors.

Other stakeholders: actuaries generally work with and rely on other advisers and stakeholders. For example, pension funds appoint external investment managers to allocate their asset portfolios. The decisions of these other professionals can be majorly impacted by resource constraints and actuaries will need to work with them to develop methodologies for dealing with these issues.

Impact on non-life insurance: this section has concentrated on long-term savings vehicles such as pension funds. Extensive literature elsewhere[824] deals with the impact of climate change on non-life insurers. However, resource constraints could potentially change the risk profile of many other insurance policies and crucially from an actuarial perspective, could

[823] Actuarial Profession (2009) The Actuaries' Code: A modern statement of principles for a growing profession
[824] For example, Bruce, N Cernesson, C Connell, R Fulcher, G Gardner, L Hawellek, D Herweijer, C Jewson, S Masi, L Maynard, T Mistry, V Rochester, D Silver, N Smith, L Stainforth D (2007) *The Impact of climate change on non-life insurance* GIRO

mean that future risk diverges from past risks, and, like climate change, impact investments and future business as well as liabilities.

Fiduciary risk: There is an increasing argument that the finance sector now has enough information to be held legally responsible for bad risk management associated with resource constraints and climate change. Quayle Watchmen Consulting[825] state that it is 'necessary for investment management agreements or the equivalent contract between pension funds and asset managers to use environmental, social and governance language in order to clarify the expectations of the parties to the contract'. This is already being tested in the courts with respect to climate change impacts and corporate negligence.

For example, in February 2008 approximately 400 residents of Kivalina, Alaska filed a lawsuit against over 20 large carbon emitters including ExxonMobil and BP. The claim for public nuisance could be worth up to $400 million. Legal actions of such nature (for example, in the case of tobacco) can take decades to resolve therefore the risk of legal action will remain uncertain for corporations, communities and the managers of capital.

Opportunities for actuaries
Actuaries are uniquely qualified to advise on areas of long-term risk, and the financial implications thereof. Therefore any organisation, both in actuaries' existing client universe or not, that are potentially affected by the direct and indirect implications of resource constraints could potentially be advised by actuaries. Particular examples:

Governments (including international organisations such as UN, World Bank and OECD): Governments have to make long-term planning decisions, many of which could be impacted by resource constraint issues. The discussions and models within this paper has also shown that the implications might have a much wider impact than might be expected, for example on economic growth, the ability of people to pay back debt and on financial savings vehicles such as pension funds. Actuaries already advise governments on such areas as climate finance, energy policy and valuing nuclear liabilities, so the actuarial profession and individual actuaries are well placed to work with government on the areas covered in this paper.

Corporations: many corporations make long-term infrastructure and planning decisions. These would normally fall outside the field of actuaries, but, again the issues covered by this paper mean that many companies could in future be exposed to long-term risks, which actuaries are well placed to advise on.

Investment managers: there have been a number of reports recently on the impact of climate change and unburned carbon reserves[826] on investment portfolios. Actuaries have not normally been involved in "stock picking" decisions. However, actuaries could and should be engaged in discussions of systemic risk as posed by this report.

[825] United Nations Environment Programme Finance Initiative (UNEP FI), July 2009, *Fiduciary responsibility, Legal and practical aspects of integrating environmental, social and governance issues into institutional investment,* A report by the Asset Management Working Group of the UNEP FI
[826] For example, Carbon Tracker Initiative (2011) *Unburnable Carbon – are the wrold's financial markets carrying a carbon bubble?* http://www.carbontracker.org/carbonbubble

8. Conclusions and commentary

This report has brought together the latest evidence on resource availability and constraints and explored how these may impact on the economy and finance. The key finding is that the future will be very different from the past. Resource constraints will, at best, steadily increase energy and commodity prices over the next century and, at worse, trigger a long term decline in the global economy and civil unrest. The actuarial profession should recognise that resource constraints do raise the possibility of a limit to growth over the medium term and should therefore dedicate some research effort into understanding how this may impact their advice.

The evidence for resource constraints is compelling and, perhaps surprisingly, the global economy remains relatively blind to this issue. Particular resources will have local impacts (such as water) while others will have global impacts (such as oil). The 1972 Limits to Growth study highlighted that following a 'business as usual' path ended in global economic and societal collapse by the middle of the 21st century. This is the path that economic development has continued to follow for the past 40 years.

How resource constraints impact the economy is complex, uncertain and depends on a number of factors. Political and market responses to the challenges faced by resource constraints will have far reaching consequences which need to be better understood and better modelled by decision makers and their advisors. To a large extent the impacts can be managed, or at the very least influenced.

Does the current 'no growth' economy in developed countries give us enough time to innovate or does it distract us from our real challenge? Will the increasing cost of resources result in investments into new methods of doing things or merely increase our investments into business as usual? Will any individual, organisation or sector take responsibility for managing a transition to a new economic paradigm or will society force this responsibility onto them in time (or too late)? Modelling such a high impact set of issues is critical not just for actuaries but also for society as a whole.

8.1 Responding to the challenge

In this report we explored 4 different scenarios associated with resource constraints:

- Business-as-usual
- Price driven change
- Regulation driven change
- Consensus driven change

These scenarios explored the implications of markets and/or government responding to the resource challenge with a long or short term focus. None of these scenarios is likely to played out in reality however they allowed us to examine the implications of resource constraints for society and how these may impact actuarial advice.

The output of each scenario was as follows:

Scenario	***Pessimistic predictions***	***Optimistic predictions***
Business as usual (market & government short term focussed)	*Long term global economic decline (based on energy availability) and local economic decline (based on food and water availability)* **Actuary case study scenario: Severe Decline (B1)**	*Slightly delayed long term global economic decline* **Actuary case study scenario: Islands of stability (B2)**
Price driven change (market long term, government short term)	*Some local long term declines in developing & emerging countries (water and food availability and penetration of new technologies into certain markets pushing back development gains) but major global economic decline averted* **Actuary case study scenario: Wage stagnation (P1)**	Major *global economic decline averted and fewer regions impacted by local declines* **Actuary case study scenario: Labour shortage (P2)**
Regulation driven change (government long term, market short term)	*Some local long term declines in all countries (technology fails to change fast enough) and long term global economic decline follows as market failures are widely seen and cannot be managed* **Actuary case study scenario: Financial repression (R1)**	*Fewer local declines but global economic decline follows as market failures are seen and cannot be managed (possibly delayed from the pessimistic prediction)* **Actuary case study scenario: Partial decline (R2)**
Consensus driven change (market & government long term)	*Some local declines (water and food) however global growth stabilises based on new technologies* **Actuary case study scenario: Partial adaptation (C1)**	*Fewer local declines and global economy stabilises* **Actuary case study scenario: Green growth (C2)**

The implications of resource constraints are clear – there are a hidden set of variables not currently included in standard economic modelling that could have a significant impact on the economy. Therefore, resource constraints, including climate change impacts, will have a broad impact on actuarial advice – in particular that related to investment and insurance (life and non-life).

In the report the scenarios above were used to explore the possible impact on the overall economy. The implications for discount rates, inflation and demographics were outlined to help put constraints around key variables used in current actuarial models. The optimistic and pessimistic predictions under each scenario were then used as a backdrop into a case study on actuarial advice (see table above for actuary case study scenario titles). Given that pensions investing is clearly a long term issue this was the focus chosen for the case study.

From the scenario runs it was clear that the potential impacts of resource constraints are varied, complex and significant.

The overall conclusion of the modelling exercise undertaken in this report is that if future economic growth is limited by resource constraints, then the impact on a long term savings vehicle such as a pension fund would be profound and actuarial projections are not currently taking this into account.

The Universal owner hypothesis[827] is usually used as an argument that investors and investment advisers would naturally take proactive action in managing the risks to the economy as a whole over time. However, there is inherently a risk in moving the entire economy from one model to another – the 'transition' risk. Therefore, there is a strong counter argument against the hypothesis, and current investor behaviour seems to follow this counter argument. Large fund owners (or funds that are passively managed) are exposed to the risks of the entire economy along with all their colleagues. If one fund manager altered their investment decision making process towards one which took into account resource constraints (for example, asset allocation mandates) they would be exposed to different short term risks than the other funds. Therefore, a Universal owner is incentivised to continue to invest in business as usual as they are measured against their peers in the short term and do not have the responsibility to tackle the wider correlated and systemic risks.

These wider risks are the responsibility of the 'whole' which no one person has control over. Consequently those risks go unmanaged. In respect of the career of the individual investor, it is better to follow the herd off the cliff than to step to one-side and get eaten by a lion before you even reach the cliff. The business as usual model will not automatically manage these risks.

To counter the Universal owner tendency to all 'jump of the cliff' together actuarial advice needs to become more aware of potential resource constraints and their implications. Actuaries need to become conversant in a number of issues which are not within their traditional range of expertise, such as the relationship between energy and other resources and the economy and the economic impacts of climate change.

8.2 The future: Questions for the Actuarial Profession

In this report we modelled the potential impact of resource constraints on a simplified pension scheme. It showed that this impact could be potentially catastrophic to the sustainability of the scheme.

The following are suggested questions which could help frame future work for the actuarial profession:

[827] Trucost, 2011, *Universal Ownership: Why environmental externalities matter to institutional investors,* UN Principles for Responsible Investment & UN Environment Programme Finance Initiative

The role of the actuary

- Should the profession investigate a range of "future scenarios" and engage with the membership on these?
- How best should actuaries communicate emergent risks?
- Do actuarial standards need review in this context?
- If these risks are modelled how should actuaries present this information to help inform political decision making?
- What is the most useful measure (or set of measures) of these risks?

Actuarial methodology

- What sort of changes of circumstances might give rise to volatility and step-changes in financial and demographic variables?
- How key is continued economic growth to the institutions and financial products modelled by actuaries? What would actuarial models look like in a low growth world?
- What is rational savings behaviour, and hence how should savings and risk management vehicles be designed in a low growth world?
- How can future low probability, high impact events (extreme cases, contingent scenarios and catastrophic risk) be modelled?
- Are correlated risks associated with resource constraints and climate change being recognised in investment and business strategies?

The impact of resource constraints

- Which resources or combination of resources, if any, could give rise to systemic economic risks and under what time frame?
- What effect might systemic economic risks have?
- What are the implications of resource constraints and systemic risk for capital market regulators?
- How may investments be affected by future political responses to resource constraints and climate change?
- What are the implications for enterprise risk management (ERM) of the risks associated with resource constraints and climate change?

8.2 Next steps

The Resource and Environment Group (REG) was established by members of the Actuarial Profession to consider how resource and climate change issues may impact the profession.

It is clear from the evidence gathered in this report that actuarial advice may be significantly impacted by resource constraints. In particular resource constraints could lead to a global economy of very low, or no growth.

REG, and the actuarial profession, should continue to develop and build the evidence for resource constraints impacts and understand in more detail how these variables can be built into actuarial models. It should also communicate with other organisations, such as corporations, academia and government, in a two way dialogue, to be able to obtain the latest information and to help these organisations with long-term decision making processes and research in this field. The profession should consider using its voice to comment on these issues and how to bring a long term risk focus into decision making.

Savings vehicles have evolved in a particular economic and legislative environment, this report questions whether the future may be different. If we were to enter into a time of low economic growth and therefore low asset returns, what would this imply for the design of such a vehicle, its viability or even the economic justification for saving?

The actuarial profession is very well placed to explore these complex risk issues in more detail.

9. Further Reading

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making financial sense of the future

Maclaurin House
18 Dublin Street
Edinburgh · EH1 3PP
T +44 (0)131 240 1300
F +44 (0)131 240 1313

Staple Inn Hall
High Holborn
London · WC1V 7QJ
T +44 (0)20 7632 2100
F +44 (0)20 7632 2111

Napier House
4 Worcester Street
Oxford · OX1 2AW
T +44 (0)1865 268 200
F +44 (0)1865 268 211

Hong Kong
2202 Tower Two
Lippo Centre
89 Queensway
Hong Kong
T +852 2147 9418
F +852 2147 2497

www.actuaries.org.uk