Climate Change and Resource Depletion: The Challenges for Actuaries

Review of Literature 2011

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Abstract

Energy is the key factor in industrial and agricultural productivity, transport and domestic existence. It is the basis of our current economic system. The predominant sources of energy for our modern society are fossil fuels and evidence indicates that the end of their unconstrained availability is imminent. In this review we examine current thinking on our dependence upon fossil fuels, including their potential impact on the economy and climate, and our lack of preparedness for a future where their availability becomes supply-constrained. The review highlights significant exposures to these risks which have not, as yet, been adequately addressed. Current evidence suggests that these issues should be more widely recognised as being among the dominant themes of the twenty-first century. They are fundamentally challenging to our current ways of thinking.

Keywords

Climate, economics, insurance, resource depletion, risk, sustainability, peak oil, energy security

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2 EXECUTIVE SUMMARY

2.1 *Executive summary*

2.1.1 Energy is the key factor in industrial and agricultural productivity, transport and domestic existence. It is the basis of our current economic system. The predominant sources of energy for our modern society are fossil fuels and evidence indicates that the end of their relatively unconstrained availability is imminent.

2.1.2 In the opening sections of the review we examine the themes of climate change and resource depletion and consider the impacts these issues may have for actuaries. Some of the current thinking on our dependence upon fossil fuels, including their potential impact on the climate, highlights a lack of preparedness for a future where their availability becomes supply-constrained.

2.1.3 Subsequently we review 21 papers on a range of topics and have organised them into six subject areas: Concepts; Current Status of Resources; Current Status of Climate Science; Economic Responses; Institutional Investment Issues; and Risk Management and Uncertainty. Each review provides a summary of the paper, a critique and then some consideration of the actuarial implications and the importance of the paper.

2.1.4 The review highlights significant exposures to these risks which have not, as yet, been adequately addressed. This of course has profound implications for any long-term planning and allocation of resources.

2.1.5 Current evidence, particularly research into peak oil, (see section 4.3), suggests that these issues need to be more widely recognised now as likely to be one of the dominant themes of the twenty-first century. They are fundamentally challenging to our current ways of thinking. We suggest that actuaries must understand these issues in order to communicate the impact of these risks to their clients effectively, and for the profession to be serving the public good adequately.

2.1.6 We hope that this review will stimulate research and constructive debate in relation to these crucial topics. The Institute and Faculty of Actuaries has commissioned research to examine questions of resource and environmental limits to economic growth. We expect that the first findings from this research will be available in 2012.

2.1.7 As actuaries we are well placed to understand the risks posed by dwindling resources, climate change and degradation of our biosphere and we can communicate their impacts on the problems our clients ask us to solve. We should not present unbalanced information or unsubstantiated opinion, nor necessarily become vested in conclusions outside of our expertise. We only need to highlight the potential range of outcomes to these challenges, and realise that unacknowledged risks can carry the greatest threats.

3 INTRODUCTION

3.1 *Introduction*

3.1.1 Welcome to the 2011 edition of the Resource and Environment Group (REG) Literature Review: "Climate Change & Resource Depletion: The Challenges for Actuaries". It is intended to build on the first edition in 2010[1] which provided a wider review of resource and environmental issues and the potential impact on each actuarial practice area. In this edition of the Review, we focus on the issue of declining resource availability, particularly energy security and fossil fuel reserves, and the effect on the global economy.

3.1.2 For practical reasons this review cannot include all topics related to sustainability, and we have limited our reviews to key papers in the fields which are covered. We acknowledge that opinions may diverge within each topic and that other papers could have been chosen. However, we believe that the papers we have reviewed provide a useful contribution for those wishing to gauge current thinking and trends, particularly for actuaries wishing to understand the potential long-term impacts for their clients, employers and the profession at large.

3.1.3 REG is a Member Interest Group of the UK actuarial profession with over 400 members drawn both from actuaries and from the wider sustainability community, in the UK and overseas. REG therefore brings together multi-disciplinary interests, including climate scientists and environmental economists, to assess the financial impact of resource and environment issues. The Literature Review is compiled from reviews submitted by individual members of REG and this year 18 members have contributed. The editors would like to extend their sincere thanks for the volunteers' efforts.

3.1.4 We hope that this review will stimulate constructive debate and further research by actuaries in relation to these crucial topics.

[1] See http://www.actuaries.org.uk/research-and-resources/documents/climate-change-and-resource-depletion-challenges-actuaries .

4 ENERGY SECURITY AND FOSSIL FUELS

4.1 *Fossil fuels as the primary energy source*

4.1.1 The central position that energy holds in the global economy does not appear widely appreciated. The harnessing of fossil-fuel based energy has divorced us from our dependence on capturing contemporaneous solar energy. With it, a substantial energy surplus has permitted the release of labour from food production. In combination with this surplus workforce, we have created industrial, consumer and financial sectors which dwarf agriculture in their monetary scale. This chart[2] shows the rapid expansion, and expected contraction, of fossil-fuel-based energy use over a ten thousand year period. Due to the finite nature of the resources used, this will occur only once in human history:

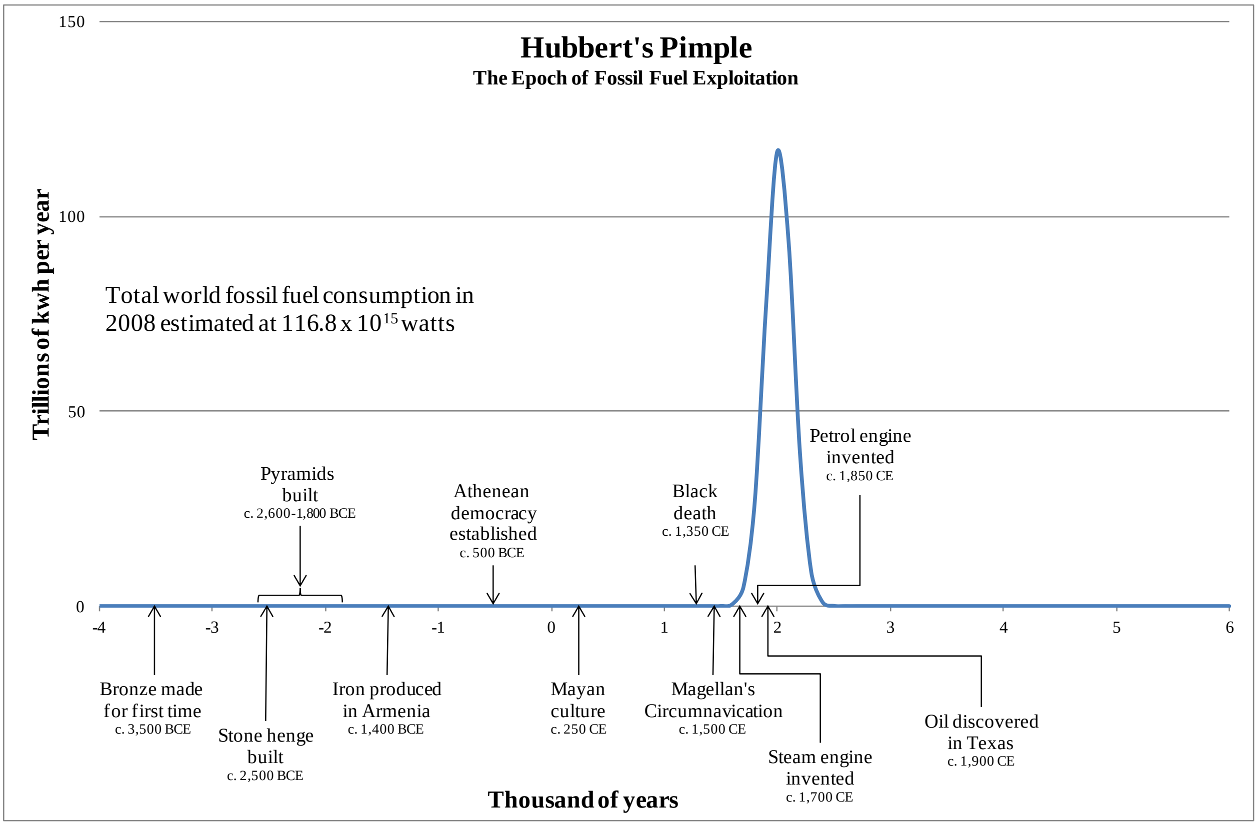

Fig 1: After Prof. Hall, C. 'Hubbert's Pimple', State University of New York, NY USA.

4.1.2 Fossil fuels enabled an increase in productive capacity without which the rising population in that period would have faced declining real wages, causing economic growth to stall before it took off[3]. The "positive checks" on population hypothecated by Malthus (e.g. hunger, disease and war) could have dominated, bringing the population and economy into balance with the energy flux through the natural environment.

[2] Whilst the exact timing of the peak shown is debateable, there is strong evidence to suggest that it will be reached in the early part of this century. See *Paper 7*.
[3] Wrigley, E. A. (2010), *Energy and the English Industrial Revolution*, Cambridge University Press, Cambridge, UK

4.1.3 Our economy has become fundamentally dependent upon fossil fuel based energy supplies. The chart below illustrates the scale of the challenge faced in substituting renewable energy supplies for non-renewables: worldwide in 2010, only 7.8% of energy consumed is estimated to come from renewable sources.

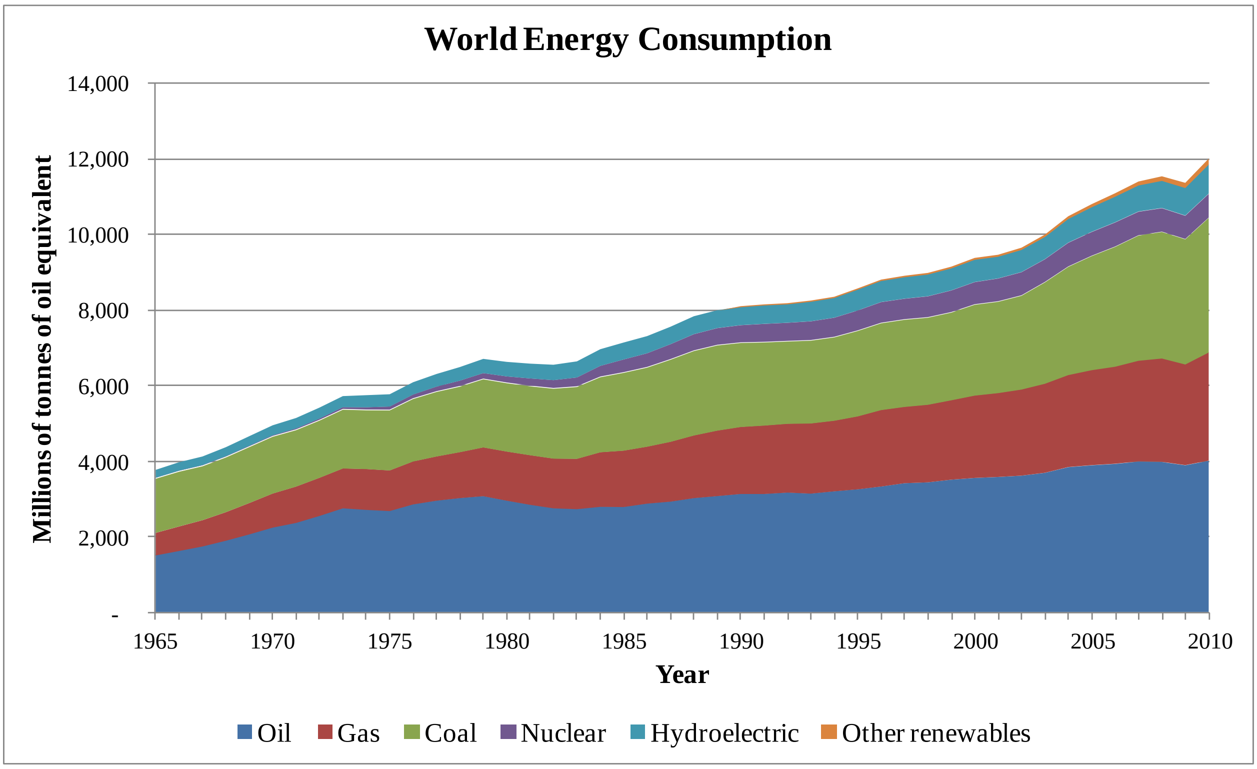

Fig 2: Presentation of data from the *BP Statistical Review of World Energy 2011*[4]

4.1.4 To illustrate the point further, in the UK electricity generation relies almost exclusively on non-renewable inputs (natural gas 40%, coal 32% and nuclear 17%)[5] with renewables contributing approximately only 7%. The UK has been a net importer of natural gas since 2004[6] accounting for around 40% of our supply[7].

4.1.5 In the UK current energy consumption per capita is estimated to be more than ten times greater than consumption per capita in 1600[8], when the economy was mostly agrarian and the population was estimated to be c. 5.5m.

4.2 *Advantages and disadvantages of fossil fuels*

4.2.1 Fossil fuels have two great advantages. Firstly they have very high energy density in that they contain a large amount of energy per unit mass. This has meant that we are able to benefit from huge amounts of trapped energy, either directly as oil (e.g. petrol and diesel), or indirectly via electricity supplied to us by electricity transmission networks. Modern industry exploits economies

[4] http://www.bp.com/sectionbodycopy.do?categoryId=7500&contentId=7068481
[5] UK Department of Energy & Climate Change, Electricity Statistics, data last updated 28th July 2011: http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/source/electricity/electricity.aspx
[6] United States Energy Information Administration (2010) 'United Kingdom country analysis brief'. Available at http://www.eia.gov/EMEU/cabs/United_Kingdom/pdf.pdf Accessed Sep 2011
[7] Simpson, J., Min, K-S. (2011), *Gas Emergency Policy: Where do IEA countries stand?*, International Energy Agency, Paris, France. Available at http://iea.org/papers/2011/gas_emergency_policy.pdf Accessed Sep 2011
[8] Warde, P. (2007) *Energy Consumption in England and Wales, 1560-2000*, CNR, Naples, Italy

of scale by concentrating technology and productive capacity in relatively small geographical areas. Fossil fuels provide the highly concentrated energy supplies they need. Secondly, their extraction is not subject to the vagaries of weather. This has enabled us to disconnect our consumption patterns from the limits of the natural and volatile cycles of nature.

4.2.2 What is now becoming readily apparent is that fossil fuels have two great disadvantages as well. Firstly, their use releases carbon dioxide (CO_2) which causes anthropogenic climate change. The extent to which global temperatures are sensitive to atmospheric CO_2 concentrations is a critically important area of research. A recent research paper by Weitzman (*Paper 20*) reviewed here finds that in the absence of strong mitigating action, catastrophic climate change cannot be ruled out with a high degree of confidence. The potential for this level of climate change appears not to be sufficiently taken into account in policy responses. That the current level of CO_2 level is c.390ppm and rising by almost 2ppm a year[9] is a grave cause for concern. Mabey and Silverthorne (*Paper 21*) propose a three-tier risk management framework which includes contingency plans should a high level of warming occur.

4.2.3 Secondly, supplies of fossil fuels are finite. The current status of oil reserves, as the primary resource used in transportation, and as the fossil fuel with the most limited reserves are explored by Owen, Inderwildi and King (*Paper 7*). The degree to which our economy is adversely affected by reduced energy availability will depend upon the extent to which we have substituted our fossil energy supply with renewable or alternatives supplies before the major impacts of supply-constrained consumption are felt. Even if the decline in oil supplies is not yet imminent, we may already be feeling the increased volatility of oil prices caused by the approach to the global peak of oil production.

4.2.4 Current global policy seems to be based upon two assumptions. Firstly, that constraints in energy supply will not have an impact on economic growth. Secondly that technology combined with free markets will provide access to alternative energy sources to replace declining and increasingly costly fossil fuels. Heinberg (*Paper 4*) indicates that it is unlikely that any mix of currently available technologies will be able to supply current energy demand let alone one which continues to grow.

4.2.5 The great advantages of fossil fuels over agrarian energy sources have enabled a meteoric rise in the productive capacity of our economy, and a concomitant rise in population, consumption and quality of life. The challenge we now face is to find a response to their disadvantages, both in mitigating and reducing climate change and in substituting for them with sustainable sources.

4.3 *Peak Oil*

4.3.1 In 1956, M. King Hubbert wrote a paper in which he hypothesised that for any oil field, the peak in extraction occurred when roughly half of the available reserve has been extracted. This paper, which is reviewed here (*Paper 1*), has subsequently sparked off a whole area of research in ‘peak oil’.

4.3.2 Most famously his method predicted that oil extraction in the US would peak between 1965 and 1970. This prediction was dismissed at the time[10]. In fact it was accurate, with the US peaking in its extraction of oil in 1970.

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[9] See Hansen and Sato Paper 9
[10] Heinberg, R. (2003) *The Party’s Over. Oil, War and the Fate of Industrial Societies*, Clairview Books, East Sussex, UK, p.275

4.3.3 There is little doubt that the principles behind Hubbert's theory are sound and there will be a significant decline to the volume of oil extraction on a global scale, with the potential for substantial implications for the economy. What are much less clear are the shape of any decline and the length of time over which this might occur. Whilst estimates and quality of available reserves take a wide range of values, the most certain and directly available oil is clearly increasingly limited. Owen, Inderwildi and King (*Paper 7*) posit that proven and probable conventional oil reserve reporting provides the figures of most use and these may show current reserves are only between 850 billion barrels (Gb) and 900Gb. This would provide as little as 27 years of supply at current consumption rates assuming production at these rates can be maintained (c.85 million barrels per day) even excluding compounding increases in consumption.

4.3.4 Estimates of the availability of unconventional oil reserves show much greater volumes, although their economic viability and the degree to which the energy consumed during their extraction and delivery to market is largely ignored in providing these figures. Future supplies of oil will almost certainly come from fields further from market (e.g. the arctic) or from lower quality deposits (e.g. tar sands) increasing the infrastructure requirements of the oil industry.

4.3.5 The recent volatility of oil prices seems to have been brought about by two factors. Firstly, as humanity has used the most accessible, and therefore cheapest, sources of oil we have been forced to extract more costly and lower quality resources. Recent research[11] by Cambridge Energy Research Associates has indicated that the marginal cost of new extraction is in the region of $\$USD_{2007}$ 85 per barrel. Secondly, oil demand is directly correlated to economic activity, setting the stage for substantial swings in oil price linked to cycles in economic activity, which may be exacerbated by speculative investment practices.

4.3.6 It is very likely that the supply of oil will decline well before oil reserves run out. We suggest that the key risk for actuaries to be aware of is the impact on the economy of a declining availability of supply of oil, not the ultimate amount of oil that is available for extraction.

4.4 *Geopolitical and economic implications of peak oil*

4.4.1 As mentioned above, high oil prices have been shown to be associated with economic recessions. Tverberg's paper (*Paper 16*) draws on analysis suggesting that the level at which oil prices presently create recessionary circumstances is c. $\$USD_{2008}$ 85 per barrel. It is interesting that this price is also estimated to be the marginal cost of new extractions, thus highlighting the energy dilemma: based on this analysis, sustained and steady economic growth, at least in the developed world, is likely to be challenging.

4.4.2 One plausible scenario is that as oil prices rise, economic activity is curtailed leading to lower oil demand, and oil prices falling back. These lower oil prices then stimulate the economy, leading to renewed demand, which in the absence of increased supplies force prices up again, with the consequence being a volatile oil price.

4.4.3 Price volatility also reduces the predictability of future revenues from oil extraction which thereby increases the hurdle rates applied in the assessment of new capital projects to bring on future supply. This is likely also to impact other capital investment proposals across the economy in a similar way, particularly where the link between oil prices and economic activity is most evident.

[11] CERA (2008) 'Ratcheting Down: Oil and the Global Credit Crisis', CERA, 14/10/2008. Available at http://www2.cera.com/news/details/1,2318,9813,00.html Accessed Sep 2011

This may create an especially difficult problem for projects investing in renewable energy sources which have long pay-back periods and investment horizons of 20 years or more.

4.4.4 Additional problems are likely to be faced by oil importing regions, such as the OECD. As domestic demand increases within oil exporting nations, political pressures are likely to lead to a preference to supplying domestic populations prior to world markets. The consequence will be an accelerated reduction of oil availability to importing nations, with the concomitant impacts on economic activity caused by the likely higher prices. This is sometimes referred to as the Export-Land[12] problem.

4.5 *Energy Return on Energy Invested (EROEI)*

4.5.1 The concept of EROEI is a simple one to grasp, but a difficult quantity to measure. EROEI is the ratio of the energy obtained from an energy source to the amount of energy used in extracting that resource. For instance, an EROEI of 10:1 means that for every joule of energy used in the lifetime of an energy source (through commissioning, supply and decommissioning) the energy source will yield 10 joules.

4.5.2 The EROEI of an energy source is important because it is the energy surplus that facilitates industrial economies. This is drawn out in more detail by Morgan (*Paper 3*).

4.5.3 Heinberg (*Paper 4*) outlines recent research on the EROEI of 18 energy sources. There is a range of estimates of the EROEI for most technologies but there is a general consensus around the ranking of technologies. Firstly, the EROEI on conventional fossil fuels (e.g. coal, oil and natural gas) is the highest, with variation depending on location and quality, but with figures ranging from 20:1 to 80:1. Second come a series of technologies (PV solar, wind, hydropower, nuclear) which have EROEI between 5:1 and 40:1 in the right circumstances. Third come what might be termed unconventional fossil fuels (tar sands and oil shale) and renewable energy carriers (biodiesel and bio-ethanol) which have EROEI measures in the low single digits.

4.5.4 The challenges for society could be met by a combination of two broad themes: firstly reducing energy consumption whilst minimising the economic impact; and secondly developing reliable energy sources which can rapidly replace fossil fuels. In 2010, renewable energy sources contributed only 7% of UK electricity generation[5]. The UK is a net importer of oil, natural gas and coal which account for more than 90% of UK electricity generation[13]. There are therefore clear risks for the UK in "keeping the lights on", which have been highlighted in part by the white paper on Electricity Market Reform by the Department of Energy and Climate Change[14].

4.6 *Is there a problem?*

4.6.1 It would be wrong in this discussion to ignore alternative opinions on sustainability issues. The achievements of human beings have been vast and the possibility that mankind may be able to offer a technological solution to these challenges should not be ignored.

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[12] The name comes from the Export-Land Model, attributed to oil geologist Jeffery Brown, which hypothesises about an oil exporting country called "Export Land".

[13] UK Department of Trade and Industry (2007) *Meeting the Energy Challenge: A White Paper on Energy*, DTI, UK Government. Available at http://stats.bis.gov.uk/ewp/ewp_full.pdf Accessed Sep 2011

[14] Department for Energy and Climate Change (DECC) (2011) *Electricity Market Reform (EMR) White Paper 2011*, DECC, UK Government. Available at http://www.decc.gov.uk/en/content/cms/legislation/white_papers/emr_wp_2011/emr_wp_2011.aspx Accessed Sep 2011

4.6.2 We present here a brief outline of what may be described as the "mainstream economist" position on resource depletion. To simplify, this is that scarcity of a resource would increase its price. Higher prices would incentivise consumers to use less energy, suppliers to innovate and users to substitute alternative, cheaper fuel sources. A slightly more detailed analysis would indicate that the supply curve for a given resource would shift to the left, increasing price and reducing demand. Taking oil as an example: in the short term price increases would mean that people would use less of it (for example, people would try to drive their car less, by cutting out unnecessary journeys or taking public transport); in the medium term agents would be expected to take more drastic action such as purchasing more fuel efficient vehicles, changing lifestyle patterns, and companies might source goods more locally to reduce transport costs. In the long run the increased prices would drive innovation, for example incentivising car companies to speed up development of electric cars.

4.6.3 A long term perspective is elucidated by Ridley (2011)[15]. He argues that societies and economies evolve to overcome problems, and human ingenuity has overcome all problems it has faced and is likely to continue to do so in the future. As a result we are wealthier and happier than at any time in the past. This is a result of a process of evolution. So again, using oil as an example (and also using the rationale of Beinhocker (2007)[16]), this would work as follows: the price of oil would increase because of the reduced supply. Some companies use or sell goods that require a lot of oil but have evolved and prospered in an oil-abundant world. However, as the world becomes oil constrained, the "fitness landscape" changes – i.e. the economic environment, just like dinosaurs these companies are no longer competitive and are out-competed by companies that use less oil. The landscape of companies changes, but the economy still delivers the same or better output, but uses less oil in doing so.

4.6.4 Technology and efficiency gains undoubtedly have a major role to play. However, the evidence detailed in this review strongly suggests that steps outlined above will be insufficient to provide for a sustainable future, within any reasonable timescale.

4.6.5 Despite the hesitant steps taken by many politicians, global institutions are increasingly addressing the issue of a future with less dependence on fossil fuel energy sources. However, the main driver behind this work has been facing the risks posed by anthropogenic climate change rather than resource limitations. We review papers by the OECD and the UN on this subject (*Paper 13* and *Paper 14*) and the transition to a low-carbon economy. Progress is being made, although the speed of reforms is, ironically, glacial. Further, there are concerns that more recent scientific evidence indicates that the policies put in place to achieve the targets adopted will not be sufficiently effective. Hansen et al (*Paper 9*) set out some of these concerns.

4.6.6 There appears to be a fundamental assumption at the heart of economic and fiscal policy of governments around the world that continued compound growth in Gross Domestic Product (GDP) is both possible and desirable. Whilst this is to be expected in the developing world, in the developed world the extent to which growth may be limited by resource constraints (e.g. of energy, minerals, water) seems to receive little attention. Renewable energy supplies face great challenges[17] in supplying the volumes of energy consumed by the world today, let alone the energy consumed by a world in which living standards and energy consumption have risen for the citizens of less-developed nations to the levels enjoyed by the developed world today. Jackson (*Paper 11*) offers a view of the world which separates the concepts of prosperity and growth, particularly in the developed world.

[15] Ridley, M (2011) *The Rational Optimist*, Fourth Estate
[16] Beinhocker, E (2007) *The Origin of Wealth*, Random House Business
[17] See http://www.withouthotair.com/ by David MacKay

4.6.7 It is generally assumed that peak oil will cause prices to rise leading to market forces bringing previously marginal extraction capacity online stabilising supply-demand imbalances; albeit at a higher price. This has been experienced in the recent past. However, it misses a number of key observations. Supply constraints mean that even after market forces have worked to bring in more supply there may still be less oil and therefore energy available than before the price increase. The Export Land model suggests that there is a risk of a more rapid decline of oil available to importing nations compared with the overall decline in world oil supply.

4.6.8 Finally, as these effects occur, the capital requirements of renewable energy projects will increasingly compete with those of marginal fossil fuel extraction. As the total amount of energy available to the global economy declines, there is a risk that there will be a bias towards proven technology even where this is polluting and limited in longevity. The large amount of sunk costs in fossil fuel based infrastructure also are likely to create a bias towards fossil fuel. Without significant government intervention in markets there is a real risk that sufficient energy will not be available to invest in renewable energy supplies at the point that they are most needed to replace fossil fuels.

4.6.9 If the total available energy in the economy starts to decline, GDP may still be permitted to grow if energy efficiency rises at or above the rate of decline of energy inputs. This approach is equivalent to "decoupling" GDP from its energy inputs. However, this process must have ultimate limits unless our economy can become a perpetual motion machine. We review an OECD paper (*Paper 13*) which highlights that absolute decoupling, whereby the absolute amount of a resource used declines, is extremely rare. The challenge of achieving absolute reductions in energy and resources used is significant, particularly when factoring in energy consumption per capita for a rising global population and the high energy requirements of product research and implementation. Any model of future economic growth is therefore more realistic if it takes energy availability and efficiency into account.

4.6.10 The Institute and Faculty of Actuaries has commissioned research into resource and environmental limits to economic growth. We expect the first results from this research to be available in 2012. We hope that this research encourages wider discussion about the limits to growth both within and beyond the actuarial profession.

4.6.11 Debt-based monetary systems require growth of the money supply, supported by growth of the economy, in order that debts may be repaid with interest. If GDP growth is constrained by energy availability, and energy price increases, then the stage may be set for large-scale credit defaults. This scenario may be exacerbated by the fact that many of the world's wealthy nations are already over-indebted and without economic growth there are important questions relating to the serviceability of this debt, and of their ability to repay it. At the time of writing many commentators are questioning the assumed economic growth rates for both the UK and the USA. If economy-wide debt serviceability becomes a cause for concern, the assumptions used for actuarial projections and decision making may need to be carefully reconsidered.

4.7 *The link between the risks from energy scarcity and climate change*

4.7.1 Clearly there are two existential and related threats to our current way of life: the threat of limitations to extraction rates of our non-renewable energy sources before alternative renewable sources have been developed; and the threat of the changing climate. On the evidence in this review, energy availability seems to have the strongest short term influence on the economy, although it could be argued that the long-term impacts of climate change are of substantially more concern.

4.7.2 Clearly these issues are linked and cannot be approached in isolation. One conclusion of the peak oil threat if analysed in isolation, is that as energy security becomes increasingly threatened we should turn more and more to unconventional sources of fossil fuels. Whilst net-energy may be lower for these sources of oil and gas, it is still positive and could contribute to the future energy mix of society. However, these energy sources are substantially more polluting than conventional fossil fuels and are likely to hasten any anthropogenic climate change. Whether we will continue to use fossil fuels in the face of this evidence or whether some will be left in the ground may depend upon the order in which any public consciousness is sufficiently raised to deal with each issue.

4.7.3 We hope that widespread recognition and governmental action to reduce reliance on fossil fuels occurs in the near future, both for the reasons of climate change and for energy security. Energy security in itself is a more easily perceived threat but, without a long-term strategy to address the issues posed by peak oil, short-term mitigations may well lead to increased consumption of fossil fuels with resultant long-term implications for climate change. Technology has an important role to play, but its purpose is likely to be to create a sustainable future rather than necessarily to provide for increases in the amount of energy consumed.

5 THE OPPORTUNITIES FOR ACTUARIES & CONCLUDING REMARKS

5.1.1 There is a substantial body of evidence which points to a forthcoming reduction in the ability of the planet Earth, including both its mineral deposits and the wider biosphere, to support our current level of economic activity and way of life. Research in many different spheres has shown a widespread and varied depletion of the natural resources on which our global society and economy are founded. Aquifers used for agriculture are being depleted all over the world[18]; the essential fertiliser inputs that supported the agricultural "Green Revolution" are becoming exhausted[19]; and energetic and material inputs to our industrial system are reaching maximum extraction rates[20]. In addition, the continued ability of our planet's land, oceans and air to absorb our waste products without directly affecting our productivity appears limited. All these trends are exacerbated by population growth and economic development.

5.1.2 The world's governments, institutions and populations may not have sufficiently considered the magnitude of the challenges that issues of resource depletion create, or the rapidity with which they may arrive either locally or at a systematic level. There seems to be an assumption that technology will provide solutions, for example, through efficiency gains. In fact, more efficient use of resources has been linked to greater demand for those resources due to a lower relative cost.[21] A full exploration of the impact on our financial and economic systems that resource depletion presents is beyond the scope of this review, but given the nature of these issues and the speed at which we must face them, it seems inevitable that significant and lasting changes to our global economy will occur during the 21st century. Actuaries, with our deep and practical understanding of financial modelling and communicating long-term risk, are ideally placed to help global efforts to face these challenges and to adapt to this changing world.

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[18] See Brown, L. (2011) Chapter 2: 'Falling water tables and shrinking harvests', *World on the Edge*, Earth Policy Institute, W. W. Norton & Company Inc., New York, USA. Available at http://www.earth-policy.org/images/uploads/book_files/wotebook.pdf

[19] Cordell, D., Drangert, J-O., White, S. (2009) 'The story of phosphorous: Global food security and food for thought', *Global Environmental Change* 19 (2), pp. 292 – 305. Available at http://www.sciencedirect.com/science/article/pii/S095937800800099X

[20] See Heinberg, R. (2010) *Peak Everything: Waking up to the Century of Decline in Earth's Resources*., Clairview Books, East Sussex, UK

[21] See the Jevons Paradox.

5.1.3 The opportunities for actuaries are twofold. Firstly, given the long-term and complex nature of these issues, actuaries may place themselves at the forefront of an open exploration of them and the impact on our global financial system. In our view, there is a significant risk that the positive and negative feedback mechanisms between the environment, its renewable and non-renewable resources, and the economy, may lead to long-term deterioration in all aspects of modern economic life. Mapping out the possible implications of any decline, including likely levels of instability and economic volatility, and assessing potential response measures will be a challenging task in future years.

5.1.4 Secondly, many of our clients have a large and poorly understood exposure to these risks at present. The impact on our global, national and local institutions of all kinds may be great if these risks lead to strongly negative outcomes, and will be most profound for those who have failed to anticipate them or mitigate the impacts appropriately. As actuaries we can understand the risks posed by dwindling resources, climate change and degradation of our biosphere and we can communicate their impacts on the problems our clients ask us to solve. We should not present unbalanced information or unsubstantiated opinion, nor necessarily become vested in conclusions outside of our expertise. We only need to highlight the potential range of outcomes to these challenges, and realise that unacknowledged risks can carry the greatest threats.

5.1.5 There may be a number of areas of current actuarial practice which will be affected by the challenges of resource and environmental depletion. Whilst it is not possible to foresee their full effects on the profession or its members' clients and employers, we highlight some more obvious areas below. The fundamental challenge to actuaries may relate to the way we build our models. These issues are within a class of problems for which only limited past experience can be drawn upon to calibrate our models and produce predictions, but the fundamental relationships may be analysed and included. We have yet not built the models which provide reasonable linkages between these real-world issues and the financial assumptions we use every day. These models are likely to evolve over time but actuaries are well placed to develop them.

5.1.6 We believe that the concerns we raise here are most pressing for recognition by actuaries working in investment fields. In formulating investment strategies, reviewing investment managers, assessing investment risk or analysing investments it is essential to take account of the energy issues we have discussed, both short and long term. Additionally, for actuaries concerned with investment returns, the importance to actuarial advice may come less from the direct effect of climate change and more from regulation that arises as governments recognise the seriousness of the problem.

5.1.7 If investment strategies are formulated which recognise these risks, there is likely to be a significant increase in the usage of Socially Responsible Investment (SRI), in whichever guise matches the requirements of the institution. It might also be termed "Financially Responsible Investment". The extent to which shareholders have so far succeeded in influencing sustainable practices is debateable but some progress has been made in a number of areas. A variety of approaches have been developed in SRI already, and whilst they might not directly analyse energy security, inclusion of this factor into the investment process should be relatively straightforward. Other impacts in the investment field might include future legislative restrictions and fiscal charges on CO_2 or other Green House Gas (GHG) pollutants, and exposure to commercial litigation (like for tobacco). The impact of markets of emissions trading, for instance, needs consideration.

5.1.8 Pension funding advice typically makes assumptions of future experience in relation to investment returns and factors affecting liabilities to produce a strategy for enabling the client to be able to meet their financial commitments. If asset return estimates and discount rates are to be realistic, they must, surely, incorporate the impacts of energy supply implications. Likewise the impact on inflation of energy supply constraints should be explored further. These concerns relate not only to energy-intensive industries but to all sectors due to the inter-connectedness of our economy. In other words, there is the potential for a strong systemic risk that cannot readily be "diversified away". If it becomes accepted that historical levels of economic growth may not persist in future, and that some sovereign and corporate debt may be unsustainable, the effects on pension fund and life insurer valuations are likely to be significant (to say the least). If resource constraints become an economic fact, changed financial assumptions are inevitable.

5.1.9 Whether institutions form strategies which take these issues into account or not, actuaries should be developing an understanding of these issues as they should be reflected in their assumptions. In either case, the mismatch between current investment return assumptions and future experience if these issues are not dealt with by society, could be significant. If institutions recognise these issues, and form an investment strategy on the basis of reducing the mismatch their exposure to them creates, the long-term stability of those institutions during any periods of crisis may be increased.

5.1.10 In future the Enterprise Risk Management practice may become one of the foremost sources of expertise in these issues through their assessment process. As we have noted, considerable uncertainties surround energy security and the impacts of climate change. Any risk modelling which fails to incorporate these issues, or the range of uncertainty which surround them, is unlikely to present a fair representation of risk for any long-term project. As mentioned above, additional issues such as regulatory changes limiting CO_2 emissions or energy usage may also need to be recognised; and second order effects from a supply-constrained world such as food shortages and civil unrest may also need to be incorporated.

5.1.11 Finally, there may be a range of unexpected demographic effects alongside any economic ones. Current agricultural practices can be highly dependent on fossil fuels to produce fertiliser and transport its produce to market, and the ability to feed world populations in future may well decline, especially as populations are projected to rise. Migration may increase and fertility change unexpectedly. Economies may have lower resources available to dedicate to healthcare. With all the uncertainties associated with climate change as well, trends for increasing longevity may be altered.

6 Papers Reviewed

A CONCEPTS

1) Nuclear Energy And The Fossil Fuels (Peak Oil Theory) – Hubbert
2) The Economics Of Ecosystems & Biodiversity (TEEB) Synthesis Report – UNEP
3) Money Is Energy – An Exponential Economics Primer – Morgan, Tullettprebon
4) Searching For A Miracle: "Net Energy" Limits And The Fate Of Industrial Society – Heinberg

B CURRENT STATUS OF RESOURCES

5) 2011 World Economic Outlook, Chapter 3: Oil Scarcity Growth And Global Imbalances - IMF
6) Annual Energy Outlook 2011 – Us Energy Information Administration
7) The Status Of Conventional World Oil Reserves – Hype Or Cause For Concern? – Owen, Inderwildi & King (Smith School Of Enterprise & The Environment)
8) Special Report On Renewable Energy And Climate Change Mitigation – IPCC

C CURRENT STATUS OF CLIMATE SCIENCE

9) Paleo-Climate Implications For Human-Made Climate Change – Hansen & Sato
10) Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia

D ECONOMIC RESPONSES

11) Prosperity Without Growth – Sustainable Development Commission
12) A Blueprint For A Safer Planet - Stern
13) Towards Green Growth: The OECD Green Growth Strategy Framework – OECD
14) Decoupling Natural Resource Use And Environmental Impacts From Economic Growth – UNEP
15) Tradable Energy Quotas – Policy Framework For Peak Oil And Climate Change – All-Party Parliamentary Group On Peak Oil And The Lean Economy
16) How Limited Oil Supply Can Lead To A Continuing Financial Crisis – Tverberg
17) Global Energy Crunch: How Different Parts Of The World Would React To A Peak Oil Scenario – Friedrichs

E INSTITUTIONAL INVESTMENT ISSUES

18) Adoption Of Green Investing By Institutional Investors: A European Survey – The EDHEC-Risk Institute
19) Funding Climate Change: How Pension Fund Fiduciary Duty Masks Trustee Inertia And Short-Termism – Wood

F RISK MANAGEMENT AND UNCERTAINTY

20) Fat-Tailed Uncertainty In The Economics Of Catastrophic Climate Change – Weitzman
21) Degrees Of Risk: Defining A Risk Management Strategy For Climate Change – Mabey & Silverthorne

A. CONCEPTS

7 PAPER 1 – NUCLEAR ENERGY & THE FOSSIL FUELS (PEAK OIL THEORY)

Citation of paper:	Hubbert, M. K. (1956) *Nuclear Energy and the Fossil Fuels*. Shell Development Company.
Location:	http://www.hubbertpeak.com/hubbert/1956/1956.pdf

7.1 *Abstract*

7.1.1 This paper outlines one of the primary theories of peak oil. The author hypothecates the possible shapes of production curves for non-renewable resources, given that their usage must start and end at zero. He begins by examining production patterns of coal and oil both in the US and globally since the late 19th/early 20th centuries up to the mid 1950s as well as natural gas production in the US, concluding that "although production rates tend initially to increase exponentially, physical limits prevent their continuing to do so." As a result, the paper then explores the implications for production of uranium created by a shift to nuclear power as the main source of electricity generation.

7.1.2 The only informational inputs used by the author are a history of production of the different fossil fuels and an estimate of the remaining global reserves of each fuel. As such the methodology is simplistic but powerful in that it generates intuitive answers and produces results which can be tested.

7.1.3 Following a review of estimated world fossil fuel reserves, Hubbert predicts (from a 1956 standpoint) a) that global peak production of coal will occur around 2150, slightly later in the US; b) that global peak production of oil will occur around 2000 but earlier by around 1970 in the US; and c) that natural gas production in the US would also peak around 1970. These projections were based on assumed maximum rates of production; variations of which the author points out would either advance or retard the culmination date. In his section on nuclear power, Hubbert explores the amount of uranium required for a generating capacity of 500 GW. As the number of nuclear power stations in his model grows he shows that a significant amount of uranium needs to be held in inventory to bring in the generating capacity (i.e. through a breeder reaction). He also analyses the amount of uranium available in ores throughout the US and finds that immense reserves of uranium exist (several hundred times those of fossil fuels at that time). As such his recommendation would appear to be that the use of nuclear energy is the best way to keep generating electricity whilst avoiding the affects of peak oil.

7.2 *Actuarial implications and importance*

7.2.1 This paper introduces one of Hubbert's most important concepts, the concept of peak oil. Although no models of production patterns are introduced in the paper, the analysis, which states a) that the production of a finite resource must decline before it runs out; and b) that it is likely that the peak in production will occur around the time when one half of the resource has been consumed, is highly compelling.

7.2.2 This paper relates to the production of energy from finite resources (e.g. fossil fuels). These provide the majority of the energy that is the primary input into the global economy. The actuarial profession should be aware of, and be able to assess, the risks of the limits outlined in this paper coming to pass.

7.3 *Actuarial critique*

7.3.1 What is most intriguing about this paper is the lack of any physical argument as to why production of fossil fuels should follow a particular curved trajectory. Instead Hubbert wishes us to focus on the bigger picture: that the production of finite resources must end at zero as they are exhausted or substituted. Whilst the trajectory for production can, and should, be debated (e.g. could peak production occur in the final year of production?) the logic of a steady decline in production appears consistent with experience in individual oil fields where declines in production of 5% pa have been observed.

7.3.2 The predictions made by this paper have had mixed outcomes. The most successful was his prediction of peak oil production in the US where it is now generally acknowledged that oil production indeed peaked in 1970. This prediction was widely doubted at the time it was made.

7.3.3 The exploratory calculations carried out for production of nuclear energy have not been borne out in practice. In the paper he works through a scenario where nuclear energy produces 500 GW of power, the forecast total US electricity consumption, by around 2050. To reach this level, capacity in 2010 would need to be around 300 GW.

7.3.4 Exponential growth in nuclear capacity in the US, as required by his model, was experienced globally through the 1970s but the Three Mile Island (1979) and Chernobyl (1986) disasters reduced public support for nuclear power and the rate of growth of numbers of nuclear power stations in the US stayed constant through to the early 1990s with little growth since[22]. Average power generation rates per hour from US nuclear facilities in 2010 were estimated at 92 GW, equivalent to 19.6% of total generation during the period[23].

8 PAPER 2 – THE ECONOMICS OF ECOSYSTEMS & BIODIVERSITY SYNTHESIS REPORT

Citation of paper: TEEB (2010). *The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and recommendations of TEEB*. UNEP.

Location: http://www.teebweb.org/LinkClick.aspx?fileticket=bYhDohL_TuM%3d&tabid=1278&mid=2357

8.1 *Abstract*

8.1.1 The Economics of Ecosystems and Biodiversity (TEEB) initiative emerged from the 2007 G8+5 gathering of Environment Ministers in Potsdam. There they agreed to "initiate the process of analysing the global economic benefit of biological diversity, the costs of the loss of biodiversity and the failure to take protective measures versus the costs of effective conservation." This paper synthesises the key results of six papers produced by TEEB since that initial commitment.

8.1.2 TEEB's aim is described as the recalibration of the "faulty economic compass that has lead to decisions prejudicial to current well-being and that of future generations" and to "provide a bridge between the multidisciplinary science of biodiversity and the arena of international and

[22] Source: analysis of data available via http://explore.data.gov/Energy-and-Utilities/U-S-Commercial-Nuclear-Power-Reactors/rfjn-7hyh
[23] Source: US Nuclear Generating Statistics, Nuclear Energy Institute

national policy as well as local government and business practice". Their overarching vision is thus succinctly summarised by the authors as "making nature economically visible".

8.1.3 TEEB advocates the full reflection of the value of natural capital and ecosystem benefits in public and private decision making. For example a decision to drain Uganda's Nakivubu Swamp was averted upon assessment of its value in purifying Kampala's waste water.

8.1.4 It is suggested that ecosystem valuations should consider the following ecosystem services that contribute to human well-being and are underpinned by biodiversity:

- Provisioning services (e.g. food, water and medicines);
- Regulating services (e.g. carbon sequestration, water filtering and pollination);
- Cultural services (e.g. recreation, spiritual and aesthetic values and education); and
- Supporting services (e.g. soil formation, nutrient cycling).

8.1.5 The paper recognises that acknowledging biodiversity's value to human well-being is not enough in itself to stimulate change – translating this knowledge into incentives which influence behaviour is the key challenge in political and technical terms. Economic assessment such as that provided by TEEB is one tool to guide such action.

8.1.6 TEEB puts forward a three-tiered approach towards analysing and structuring ecosystem valuation which has strong parallels with the actuarial control cycle. The first tier is 'Recognising value', be it cultural or social value, which sometimes can be enough to stimulate sound conservation and management. The second tier is 'Demonstrating value' in economic terms so that the full costs and benefits can be taken into account for policy and business decision-making in order to aid more efficient use of natural resources. The third tier is 'Capturing value' in the market, which involves the introduction of mechanisms that incorporate the values of ecosystems into decision-making through incentives and price signals.

8.1.7 Generally, the paper argues for the reform of the false trade-offs that characterise our current relationship with nature. By reflecting the true cost of accessing resources, and by being more requiring of a 'no net loss' or 'net positive impact' on ecosystems and biodiversity we can avoid degradation and neglect of our natural capital.

8.1.8 The paper highlights some key case studies which demonstrate the application of TEEB's three-tiered approach across ecosystems, human settlements and business.

8.1.9 In conclusion, a number of recommendations are made including the valuation of net impact on ecosystems in public decision making, reform of harmful subsidies, corporate accounting disclosure of all major externalities (including environmental liabilities and net impact on natural assets and ecosystems) and a principle of 'polluter pays' (i.e. recovery of full costs of net environmental impact).

8.1.10 The authors highlight a number of challenges to adoption of their approach, including:

- How to place a value on the different services provided by ecosystems? (E.g. is it easier to value the net impact of a change rather than the ecosystem as a whole?);
- The complexity and controversial nature of the valuation process; and
- How to manage the trade-offs between traditional valuation methods which focus on private wealth, value of physical capital or assets, with public wealth i.e. the availability of natural capital for use of society including future generations.

8.2 *Actuarial implications and importance*

8.2.1 The challenges of inter-generation resource depletion raised by this paper have direct links to inter-generational wealth transfer and as such fall within actuaries' public interest role.

8.2.2 The recommendations of this paper, if implemented, could have considerable implications for the value placed on listed companies particularly if the philosophy of 'no net loss' or 'net positive ecosystem impact' becomes widely endorsed. The disclosure of the economic value of environmental liabilities could lead to a material restatement of the value of companies with high relative debt to natural resources.

8.2.3 A focus on 'no net loss' and 'polluter pays' could also lead to more volatile investment returns, as environmental incidents are likely to have more immediate, and dramatic, balance sheet impacts.

8.2.4 The concept of 'no net loss' or 'net positive ecosystem impact' may be of value to actuaries advising on socially responsible investment strategies.

8.2.5 The potential for trading in biodiversity credits (i.e. credits awarded to companies for fostering biodiversity) may be of interest to those actuaries active in, for example, carbon trading markets.

8.2.6 General insurance actuaries may find this paper inspires new rating factors for pricing. For example should early adopters of ecosystem valuation methods gain preferential public liability insurance rates to reflect reduced exposure to future 'polluter pays' claims?

8.2.7 Actuaries involved with developing countries or micro-insurance will find the discussion on how natural capital depletion has particularly acute impacts on poorer households of interest.

8.3 *Actuarial critique*

8.3.1 The paper advocates taking a long-term outlook of value when assessing ecosystems and biodiversity. This will appeal to actuaries, but some may be disappointed that few of the initiatives described extend beyond a five year time horizon.

8.3.2 The paper introduces the ideal of dual discount rates - suggesting that market discount rates are appropriate for use in valuing 'reproducibles' i.e. private goods and manufactured assets, with (implicitly lower) social discount for 'non-reproducibles' i.e. public goods and natural assets. Actuaries will find this an interesting perspective to the market-value vs long-term-valuation debate.

8.4 *Source of further actuarial study*

8.4.1 The issues highlighted by the paper offer a wealth of opportunities for actuaries to be involved in the economics and valuation of ecosystems. Examples include:

- Using our General Insurance (GI) expertise in valuing the 'natural insurance' ecosystems that provide as protection against environmental shocks.
- The need for reliable tools to assess, verify and value biodiversity impacts, including alternative value and risk metrics to net present values.
- Developing our understanding of the risks to capital values if we are as close to environmental tipping points as the authors fear.
- Bringing expertise on a greater breadth of market-consistent valuation mechanisms suited to long-term liabilities along with an appreciation of the appropriateness (or otherwise) of different 'non-market based' valuation methods (e.g. social discount rates).

9 Paper 3 – Money is Energy – An Exponential Economics Primer

Citation of paper: Morgan, T (2010). *Money is Energy – an Exponential Economics Primer*. Tullet Prebon Strategy Notes, Issue Seventeen, Tuesday, November 16th, 2010.

Location: http://www.tullettprebon.com/announcements/strategyinsights/notes/2010/SIN20101116.pdf

9.1 *Abstract*

9.1.1 This article calls for the recognition that the economy is a "surplus energy equation" should underpin the development of a new discipline of "exponential economics" – which the author argues would take an ultra long-term economic perspective.

9.1.2 At its heart the "surplus energy equation" concept acknowledges that energy inputs are required to enable the extraction of greater energy outputs and that only this surplus energy is available for discretionary uses and improved living standards. The author argues that from this perspective alone it will be appreciated how unsustainable our 'energy driven economy' has become.

9.1.3 He states "*though economists and policymakers customarily think in terms of money, that's not what the economy is really about. Ultimately, the economy is an energy equation, not a monetary one. To be slightly more precise, it is a surplus energy dynamic*".

9.1.4 His concept that 'Money is Energy' comes from the idea that "*If the economy is an energy equation, it follows that money is a tokenisation of energy*".

9.1.5 He describes the concept behind his reasoning, namely EROEI – Energy Return on Energy Invested. EROEI is based on the idea that the volume of energy in the world is split into 1) energy that is required for energy extraction, 2) energy for essentials (food, welfare, government, law), and 3) the remainder which is for consumption and investment.

9.1.6 However he argues that the energy needed to extract the remaining volume of energy in the world is likely to increase – and that this would reduce the energy available for consumption and investment – which the author argues is the foundation on which our economy is built.

9.1.7 He goes on to give interesting examples of our dependency on energy, and how it is used to leverage other resources. The implication is that in the absence of a substantial increase in energy

availability, a fall in EROEI would reduce the energy surplus and potentially cause a significant supply shock to the world economy in general.

9.1.8 The paper concludes with a call to develop the technique of 'exponential economics', or for understanding the economy as an energy dynamic starting with an effort to calibrate EROEI.

9.2 *Actuarial implications and importance*

9.2.1 There is some evidence to support the dependence of economic growth on energy inputs (see Paper 14 on decoupling growth from energy use and natural resource impacts), and, when we consider that money is given value by the fact that there are goods and services to buy with it, then it is not implausible that growth of real economic output should be strongly correlated with the growth of surplus energy availability.

9.2.2 Whilst the writer paints a pessimistic economic outlook the broad plausibility of the argument suggests that the declining availability of energy inputs to the world economy would have consequential knock-on implications for investment returns and the economy generally. This would have implications for most actuarial employers and clients.

9.2.3 The effect of the availability of surplus energy to the economy is not included in the actuarial education syllabus. This is something that should be considered in the next syllabus review for Subject CT7 (Economics).

9.3 *Actuarial critique*

9.3.1 The conceptualisation that 'money is energy' is novel, and stimulates a new way of thinking about the economy. However, we note that modern economic theory recognises only that money is a means of exchange of production, labour and capital. Energy is a very important factor of production and labour but it is not traditionally seen as a means of exchange in the context of economics, which is perhaps the author's point!

9.3.2 Classical economics would consider there to be four factors of production, land labour, capital and entrepreneurship. The article correctly highlights dependency on energy and other primary resources for production. Production is also highly dependent on the other factors of production. Implicitly the author is arguing that there are resource issues regarding energy – but he fails to present supporting facts.

9.3.3 The author presents broad-brush reasoning in support of his arguments but, perhaps due to the intended audience and the brevity of the paper, does not support them with a balanced evidence base. The lack of presentation of estimates of likelihoods to support the arguments put forward in the article may detract from the ability of objective readers to engage with its messages, particularly those who are still to be convinced of the issues presented by climate change and resource depletion.

9.3.4 This article is interesting and raises some important issues. However, its main messages get lost in the rhetoric, which is a shame as the general thrust of the argument is very relevant to the spectre of peak oil.

9.4 *Source of further actuarial study*

9.4.1 More objective and dispassionate research is required in this area (EROEI) to come to more balanced conclusions – which could then be effectively communicated to both the Actuarial Profession and the wider public.

9.4.2 Humans are essentially positive and optimistic animals. This means that communicating bad news and research to them is very difficult. This should be explicitly addressed when communicating research in the climate change and resource depletion fields or it could result in further scepticism toward the implications brought about by careful scientific research.

10 PAPER 4 – SEARCHING FOR A MIRACLE: "NET ENERGY" LIMITS AND THE FATE OF INDUSTRIAL SOCIETY

Citation of paper: Heinberg, R., (2009). *Searching for a Miracle: "Net Energy" Limits and the Fate of Industrial Society*. International Forum on Globalization and the Post Carbon Institute.

Location: http://www.ifg.org/pdf/Searching%20for%20a%20Miracle_web10nov09.pdf

10.1 *Abstract*

10.1.1 This paper seeks to answer the question of whether any combination of the most widely known energy sources could successfully supply society's energy needs at least up to the year 2100. An analysis is performed of eighteen energy sources using a set of ten proposed criteria which can be broadly grouped under the headings:

- Contribution (scale, reliability, energy density);
- Practicality (renewability, environmental impacts, dependence on additional resource, transportability, location of resource); and
- Economics; (direct monetary costs, energy returned on energy invested (EROEI)).

10.1.2 The report is intended as a non-technical examination of these issues and therefore only high-level detail is discussed for each criterion against each energy source. However, extensive references are provided for those wishing to read and investigate further.

10.1.3 Tradeoffs of the criterion are not suggested but rather presented for a comprehensive picture of each energy source. In summary, Heinberg highlights the main limitations with each of the 18 energy sources considered.

10.1.5 The five fossil fuels of oil, natural gas, coal, tar sands and oil shale have unacceptable environmental impacts and are non-renewable energy sources. In addition, oil shale has a low EROEI and Heinberg highlights the decreasing EROEI with oil and natural gas compared with the other fossil fuels listed.

10.1.6 The four alternate energy sources of hydropower, solar PV, tidal power and wave energy are found unlikely to be large contributors based on current evidence, while the data on geothermal energy ranges from indicating it to be a slight contributor to a significant contributor, so is difficult to rely upon. In addition, tidal and wave energy are seasonal and location specific.

10.1.7 The three alternate energy sources of biodiesel, ethanol and active solar thermal have low EROEI limiting the size of their potential contribution.

10.1.8 Biomass is likely to decrease as an energy source as the uses for other purposes and hence price of these natural resources increases. Similarly, energy from waste is likely to decrease as recycling becomes more widespread.

10.1.9 Passive solar energy is a potential energy solution for commercial and residential buildings rather than agriculture and industrial purposes. Therefore, its potential contribution is limited although this would mean that energy would not need to be directed towards commercial and residential buildings.

10.1.10 Wind power could potentially be a large energy contributor but is weather and location specific and also requires transportation and technology developments.

10.1.11 Nuclear energy development is likely to be limited due to safety perceptions.

10.1.12 In addition, the papers seeks to highlight that development of capacity and distribution of new energy sources and extraction of depleting energy sources will require time, energy, investment, technology and infrastructure.

10.1.13 The author concludes that future energy supplies are unlikely to be adequate to match current levels of demand and a combination of energy conservation and development of all energy sources will be necessary.

10.2 *Actuarial critique*

10.2.1 This readable paper presents a fair amount of data and explains related topics including energy transportation, storage, density and Energy Returned on Energy Invested (EROEI) clearly in a concise form.

10.2.2 The main message of the paper – that the combination of an increasing population and dwindling fossil fuels requires acknowledgement and action within a short time frame – comes across. Detailed analysis is neither followed nor required to come to or evidence this conclusion. However, more detail may have been useful in narrowing the range of estimates and giving context to the likely impact or not on standard of living.

10.3 *Source of further actuarial study*

10.3.1 Actuarial skills may be useful for region specific planning of the optimal energy mix. Energy resource availability-suitability could potentially be analogous to investment modelling techniques and demographic trends are an important input factor.

B. CURRENT STATUS OF RESOURCES

11 PAPER 5 – 2011 WORLD ECONOMIC OUTLOOK, CHAPTER 3: OIL SCARCITY GROWTH

Citation of paper: Main authors: Helbling, T., Kang, J.S., Kumhof, M., Muir, D., Pescatori, A., Roache, S., support from Song, M.K., Asdorian, G., Marina, R., Erbil, N., (2011). *World Economic Outlook, Chapter 3: Oil Scarcity, Growth, and Global Imbalances*. International Monetary Fund

Location: http://www.imf.org/external/pubs/ft/weo/2011/01/pdf/c3.pdf

11.1 *Abstract*

11.1.1 The World Economic Outlook (WEO) presents analysis and projections by International Monetary Fund (IMF) staff of the global economy. It is usually prepared twice a year, and forms the main instrument of the IMF's global surveillance activities. This review is of Chapter 3 of the edition published in April 2011. This chapter focuses on oil scarcity.

11.1.2 The IMF analysis finds that persistent increase in oil prices over the past decade suggests that global oil markets have entered a period of increased scarcity. This is unlikely to change in the near term, given the expected rapid growth in oil demand in emerging market economies and a reduction in the trend growth of oil supply.

11.1.3 Another finding is that gradual and moderate increases in oil scarcity may not present a major constraint on global growth in the medium to long term. However, adverse effects could be much larger depending on how the world copes with oil scarcity.

11.2 *Prospects for overall energy consumption and oil demand*

11.2.1 The IMF looked at historical data and concluded that high-income economies can sustain Gross Domestic Product (GDP) growth with little if any increase in energy consumption. In contrast, in low and middle income economies energy demand growth has closely followed growth in per capita income. China's energy demand has so far closely followed this pattern. At current energy prices, energy consumption in China is projected to double by 2017 and triple by 2025 from its 2008 level. However, rising prices may restrain economic growth and/or reduce the relationship between energy and income.

11.2.2 The oil price elasticity of demand was estimated. The combined result for Organisation for Economic Co-operation and Development (OECD) and non-OECD countries suggests very low short term price elasticity, with longer term price elasticity being 4 times larger, but still low. With such low oil price elasticities, if demand exceeds supply, only substantial price increases would succeed in balancing the market.

11.3 *What are the prospects for oil supply?*

11.3.1 Prospects for oil supply are strongly dependent on production constraints in some major producing economies arising from oil fields reaching maturity – the stage when field production plateaus or declines. These constraints became obvious when the global crude oil production stagnated during the global economic boom in the mid-2000s.

11.3.2 The IMF paper asks whether the broad stagnation of oil supply over the past five years is a temporary or permanent phenomenon. The answer depends on how permanently the decline in production from maturing fields can be more than offset by increased production from new or undeveloped fields, or from increased recovery from current fields. This would require continued large-scale investment, which for the past five years had been stagnating. Sustained oil price increases, however, have seen investment spending on the up, which could see the decline from currently operating fields offset up to an aggregate decline rate of 5% per year if this continues.

11.3.3 A return to the trend growth of 1.8% pa in oil production experienced during 1981-2005, despite the current investment effort, seems unlikely given field declines in some major producing countries.

11.3.4 There is considerable uncertainty about the future paths of decline rates in maturing fields, and geopolitical risks, both short and long term, remain. Therefore there is a risk of larger than anticipated oil scarcity. The possibilities include an outright decline in oil production, either temporarily or more permanently.

11.3.5 The US Geological Survey report released in 2000 estimated that there were between 1 and 2.7 trillion barrels of conventional oil still in the ground that are technically recoverable. The large range reflects the uncertainty in global oil reserves.

11.3.6 In Box 3.1, the decline rate of mature oil fields and regions is explored. Some analysts think that current decline rates of around 4% per year, are expected to increase further as the decline in large mature fields accelerates. However, past observed decline rates may not be valid for the future if a higher oil price drives increased use of technology.

11.3.7 US oil production peaked in 1970. This corroborates the view that decline is hard to reverse once it begins. However, Box 3.1 finds that the average rate of decline in the US has been steady at about 1% a year since the 1970s, giving grounds for "cautious optimism".

11.3.8 Box 3.2 states that there are large, potentially game changing, reserves of shale gas. However, it is difficult to predict the extent to which this potential can be realised.

11.4 *Oil Scarcity and the Global Economy*

11.4.1 To assess the implications of greater oil scarcity for global economic growth and current account imbalances, the IMF carried out economic modelling calibrated with oil price elasticities described in the earlier section.

11.4.2 The benchmark scenario models the effect of a reduction in the average growth rate of world oil supply such that oil supply grows at 0.8% per year instead of 1.8%.The world oil price increases by 200 percent after 20 years in this benchmark scenario, after an initial short-term price spike of 60 percent. The effect of this appears to slow annual global growth by less than 0.25%.

11.4.3 The report discusses three alternative scenarios: scenario 1 considers greater substitution away from oil; scenario 2 considers greater decline in oil production; and scenario 3 considers a greater economic role for oil, assuming that part of total factor productivity represents technologies that are only usable when there is a ready supply of oil. In this review, we consider scenarios 2 and 3, as these examine the risks to the global economy.

11.4.4 In scenario 2, oil production declines by 2% pa, a scenario which reflects the concerns of peak oil proponents, who argue that oil supplies have already peaked and will decline rapidly. In this scenario, the longer term effects are roughly three to four times as large as in the benchmark scenario, meaning they increase roughly in proportion to the size of the shock.

11.4.5 In scenario 2 the oil price increases by 200% immediately and by 800% over 20 years. Relative price changes of this magnitude would likely have nonlinear effects which are not captured by the model.

11.4.6 In the benchmark scenario, the output contribution of oil is equal to its cost share. Some researchers in the natural sciences have argued that this substantially understates the importance of energy for economic activity[24].

11.4.7 To reflect this possibility, in scenario 3, the contribution of oil to output is modelled as 25% in the tradeables sector and 20% in the non-tradeables sector (rather than 5% and 2%). The model results indicate that in scenario 3 the deterioration in all regions' GDP is larger by about a factor of two than in the baseline.

11.5 *Additional Considerations*

11.5.1 In this section the authors highlight limitations of their model. It assumes smooth transitions to new equilibrium positions in all cases e.g. financial markets intermediate a flood of savings from oil exporters. The authors point out that some of these assumptions may be too optimistic.

11.5.2 Unlike in the model, real economies have many highly interdependent industries. Several industries, for example car manufacturing, long-distance trade and tourism, would be affected by an oil shock much more seriously than others. The adverse effects of large-scale bankruptcies in such industries could spread to the rest of the economy.

11.5.3 The simulations do not consider the possibility that some oil exporters might reserve an increasing share of their oil output for domestic use. If this were to happen, the amount of oil available to oil importers could shrink much faster than world oil output.

11.6 *Actuarial implications and importance*

11.6.1 This IMF chapter makes clear the importance of oil to the global economy, and the potential impact of constraints in oil production. The potential magnitude of the impact can hardly be overstated. Impacts would include GDP growth assumptions, current account imbalances and huge flows of capital between oil importing and exporting nations. The chapter itself hints at possibly severe adverse outcomes.

11.7 *Actuarial critique*

11.7.1 This chapter provides an excellent exposition of peak oil issues. Forecasting for 20 years into the future is a difficult task, and the chapter itself sets out many of the limitations of the modelling, for example, the inability to model non-linear effects and the assumption that responses to oil scarcity will be smooth. The critique here will focus on areas where future work may provide clarification.

[24] For example. Ayres and Warr (2005) and Kümmel, Henn and Lindenberger (2002) have found output contributions of energy that range from 30% to more than 60% (oil being an important fraction of total energy inputs).

11.7.2 The benchmark scenario allows for an increase of oil supply of 0.8% per year over the 20 year period starting in 2010. This is broadly consistent with the International Energy Agency's 2010 World Energy Outlook (WEO), which projects that global oil supply will increase from 84 million barrels a day (mb/d) in 2009 to 96 mb/d in 2035 (an increase of 0.5% per year).

11.7.3 When evaluating the likelihood of the "greater decline of oil" scenario (i.e. scenario 2), we should keep in mind an apparent trend in oil forecasting. In 2004, the IEA's WEO forecast for the year 2030 predicted that global oil supply would be 121 mb/d by that year. Subsequent annual WEO's have revised this estimate downwards, until arriving at the 2010 WEO figure of 96 mb/d. Also, the 2004 WEO had a reference scenario of oil price at $USD 25 a barrel as an average over the period 2004-2030, with a special analysis of sustained high oil prices where the price averaged $USD 35 a barrel during the period. The oil price actually peaked at $USD 147 a barrel in 2008, before falling during the credit crunch and rising again subsequently to over $USD 100 a barrel again recently.

11.7.4 The natural actuarial outlook is to look for realistic worst case scenarios. One simple method to explore a realistic worst case scenario is the possibility that the elements modelled in scenarios 2 and 3, i.e. greater decline of oil and greater economic impact of oil, are both true. If this scenario occurred, the economic impact would likely be greater than an addition of the impact of each scenario independently.

11.7.5 The report discusses the energy elasticity of the economy, and the price and availability of oil, being the most important energy source. However, it does not discuss the net energy output from oil supply. Exploration, manufacturing oil rigs and drill ships, drilling, and all other activities, all use large amounts of energy. It is the net energy available to the economy after the energy used by the oil business that enables economic activity. The net energy available to use after the energy needed to extract the energy source is sometimes described as the Energy Returned on Energy Invested (EROEI). Since easily available energy sources tend to get exploited before more inaccessible sources (such as deep water or arctic oil), EROEI tends to decline over time. A full discussion of the importance of energy to the economy should address the declining EROEI of fossil fuel sources.

11.7.6 Another consideration not addressed in the chapter is that the energy content of various liquids in the oil supply varies – for example the energy content in a barrel of natural gas liquids is less than that in a barrel of crude oil.

11.7.7 The report refers to the possibility that "the increase in world savings implied by [scenario 2 – greater decline of oil] is so large that several regions could, after the first few years, experience nominal interest rates that approach zero." We would question the plausibility of the model that produces this result; what is going on here? The savings would be accumulated by oil exporting nations as a result of higher oil prices. How much, in effect, debt could be accumulated by oil importing nations before triggering default is open to question. The outcome that interest rates would tend towards zero seems far from certain, as the monetary system itself may come under stress.

11.8 *Source of further actuarial study*

11.8.1 The Institute & Faculty of Actuaries has commissioned research into limits to economic growth. Restrictions in energy supply would seem to be one key possible limit to global growth, as explained in this chapter.

11.8.2 A further investigation of realistic worst cases arising from oil depletion may be a fruitful area of actuarial study. Where models are not capable of modelling non-linear outcomes, scenario building might be used as an alternative.

11.8.3 The degree to which the financial sector, and in turn the whole economic system, would be impacted by oil supply or energy supply constraints would be a key consideration for actuaries and deserves much future study.

12 PAPER 6 – ANNUAL ENERGY OUTLOOK – US ENERGY INFORMATION ADMINISTRATION

Citation of paper:	United States Energy Information Administration (2011). *Annual Energy Outlook 2011*.
Location:	http://www.eia.gov/forecasts/aeo/pdf/0383(2011).pdf

12.1 *Abstract*

12.1.1 This detailed annual report focuses on factors shaping the US energy system over the long term with corresponding projections up to 2035. Much of the report is based on a reference case, 'AEO2011', which assumes that current laws and regulations remain unchanged throughout the projections. This scenario provides the basis for examination in the main. However, discussion also includes 57 'sensitivity' cases throughout the report which incorporate alternative assumptions exploring important uncertainty areas in technology, markets and policy. The key results within AEO2011 include strong growth in shale gas production, growing use of natural gas and renewable electric power generation, declining reliance on imported liquid fuels, and projected slow growth in energy-related CO_2 emissions even in the absence of new policy that encourages mitigation.

12.1.2 Within this model, many aspects of energy supply and issues impacting it are discussed. These range from world oil supply and price trends, to prospects for shale gas, the impact of cost uncertainty on construction of new electric power plants and the economics of Carbon Capture and Storage. Recent legislative and regulatory activities that impact energy production, energy use and as such environmental issues are also presented.

12.1.3 The report states that a few energy-intensive manufacturing industries account for the majority of total industrial energy consumption in the US. Ranked by total energy usage, the top five energy-consuming industries (bulk chemicals, refining, paper, steel, and food) accounted for 61% of industrial energy consumption.

12.1.4 Coal-fired plants continue to lead electricity output, largely as a result of increased use of existing capacity. However, their share of the total generation mix is projected to fall from 45% in 2009 to 43% in 2035 as a result of more rapid increases in generation from natural gas and renewable energy sources. Growth in gas-fired generation is supported by low natural gas prices and stable capital costs for new plants.

12.1.5 Energy-related CO_2 emissions are expected to grow slowly. Reasons include growing use of renewable technologies and fuels, efficiency improvements, slower growth in electricity demand, in part because of the recent recession, and more use of natural gas, which is less carbon-intensive than other fossil fuels. Petroleum remains the largest source of CO_2 emissions over the projection period, but its share falls from 44% in 2005 to 41% in 2035.

12.1.6 Structural changes within the US economy have had a significant impact on its energy usage. Since 1990, a growing share of US output has come from less energy-intensive services. In

1990, 68% of the total value of output came from services, 8% from energy-intensive manufacturing industries, and the balance from non-energy-intensive manufacturing and the nonmanufacturing industries (e.g. agriculture, mining, and construction). In 2009, services accounted for 76% of total output and energy-intensive industries only 6%. The report projects that services will continue to play a growing role while energy-intensive manufacturing will continue to decrease.

12.1.7 The analysis also projects the growth in electricity use from both the residential and commercial sectors from 2009 to 2035. For the residential sector the growth is only partially offset by technological improvements that lead to increased efficiency of electric devices and appliances. For the commercial sector the growth in electricity demand for new electronic equipment more than offsets improvements in equipment and building shell efficiency.

12.1.8 One projection of the report is that high energy prices and concerns about the environmental consequences of greenhouse gas emissions result in a number of national governments providing incentives in support of the development of alternative energy sources, making renewable energy the fastest-growing source globally.

12.1.9 Potential efficiency improvements for appliance standards and building codes are two other areas discussed. The analysis considers the potential for energy savings from technological improvement and the application of appliance standards and building codes. The analysis concludes that depending on the extent of the changes to standards and codes, the generated savings could approximately range from an equivalent of 100% to 200% of the energy that the US building sector consumed in 2006.

12.2 *Actuarial implications and importance*

12.2.1 Being the world's largest consumer of energy and one of the largest sources of energy production in a number of sectors, US energy production, consumption and policy has a significant impact on global energy prices and usage. As such, these issues also have a significant impact on corresponding technological and environmental issues. Additionally, many trends in the US may have parallels in other highly industrialised economies. The global economic impact will pose challenges for insurers in areas ranging from investment, pricing, and reviewing their underwriting guidelines and coverages to development of new insurance products and coverages.

12.2.2 The issues presented in the report will impact global policy, economy and energy prices. These areas have implications for the financial sector in general and insurers in particular. For instance, the 2010 Deepwater-Horizon oil drilling platform blowout in the Gulf of Mexico and the 2011 nuclear power plant destruction in Japan are energy sector incidents with very significant global economic and policy implications. In turn, such events have a direct and substantial impact on insurers' finances, underwriting and ratemaking.

12.2.3 Additionally, energy prices and economic recessions which are correlated to energy prices, directly impact business and consumers and as such their behaviour. For insurers, such issues will also have a significant impact on investment income.

12.3 *Source of further actuarial study*

12.3.1 The extent and form of technological improvements, potential changes to appliance standards, and building codes in particular may need to be considered by insurers. The nature and the extent of such changes to the underlying risks may need to be reflected in underwriting and ratemaking in the future.

13 Paper 7 – The Status of Conventional World Oil Reserves

Citation of paper: Owen, N. A., Inderwildi, O. R., King, D.A. (2010) *The Status of Conventional World Oil Reserves – Hype or Cause for Concern?* Energy Policy Vol. 38 (8).

Location: http://www.sciencedirect.com/science/article/pii/S0301421510001072

13.1 *Abstract*

13.1.1 This paper reviews public and information agency figures for global oil reserves, comparing them with estimates provided by independent researchers. Highlighting that political and financial incentives have often encouraged reserve misreporting, this paper supports the growing contention that conventional oil production may soon go into decline and that "*the age of cheap liquid fuels is over*". It concludes that conventional oil reserve estimates are best described by 2P reporting (proven + probable reserves) and therefore should be revised downwards from 1150-1350 Gb (billion barrels) to 850-900 Gb.

13.1.2 The paper shows that world 2P conventional oil reserves have been consistently in decline since 1980 (i.e. that additions of 2P reserves have been lower than the consumption of oil) and that the rate of decline is increasing. In addition, a review of literature by independent researchers carried out by the authors indicated that production is expected to decline on average between 2010 and 2015.

13.1.3 The 110 top producing oil fields (of c.70,000 fields) constitute over 50% of the world's supply with the top 20, discovered by 1959, contributing 27% of supply, of which 20%is in turn supplied by the 10 most productive fields. In 2007, the International Energy Association (IEA) found 16 of the top 20 to be in decline, with the chance of finding similar size fields now very remote. The average post-peak decline rate of the giant fields has been estimated to be in the range of 4.5% pa and 6.7% pa in the worst case, projected to result in a cumulative gap between Business-As-Usual (BAU) demand and production of c.925Gb between 2010 and 2050.

13.1.4 In light of these findings, the paper moves on to consider the prospect for other liquid fuels. In 2008 the IEA estimated that current sources of liquid fuel will only have the capacity to service just over 50% of BAU demand by 2020. The remaining 50% (c.18Gb pa) will have to be met by sources that are not in production today.

13.1.5 The paper also reviews estimates of oil price-GDP elasticity which is estimated at -0.055, meaning that a 10% rise in oil price would translate into a 0.55% GDP loss. The paper calls for the development of policies for a supply-constrained economy. These policies would act to reduce consumption and operate with a sense of urgency to introduce alternative energy carriers and effective demand side measures, such as behavioural change and adaptation. Hesitation could result in high-oil-price induced negative macroeconomic consequences in the future, demanding even more drastic policy measures to reduce oil price-GDP elasticity. This outlook should be used to build the business case for investment into alternative energy carriers, improving energy security and reducing greenhouse gas emissions in the process.

13.2 *Actuarial implications and importance*

13.2.1 The paper is a useful summary of research and public reserve figures between c.2005 and 2010. It does not present any primary research, however it draws realistic and useful conclusions from the literature which has been surveyed.

13.2.2 The paper supports the contention that production of conventional oils may soon go into decline, which contradicts the most recent forecasts from the IEA which project flat volumes of conventional oils through to 2035 and beyond. It concludes that the age of cheap liquid fuels is over and that supply and demand are likely either to diverge, or demand will fall in parallel with a supply-constrained recession in the period between 2010 and 2015.

13.2.3 That a lack of oil supply might be expected to induce a further recession will be concerning for actuaries, particularly given current pressures on sovereign debt, consumer spending and inflation. Many actuaries will not have considered the risk that economic growth might be constrained by supplies of oil, or that this might happen in the short-to-medium-term.

13.3 *Actuarial critique*

13.3.1 As no primary research is presented, there is little to critique in terms of modelling or statistics. The paper makes efforts to ensure that some caution is highlighted in using the figures, particularly around reserve figures which, by their very nature, are estimates and probability-based. The paper is well-balanced.

13.4 *Source of further actuarial study*

13.4.1 Further work validating the oil price-GDP elasticity results presented and modelling the risks associated with a supply-constrained recession would be useful. Both the probability of this occurring and the impact if it were to occur could be estimated.

13.4.2 There may be opportunities associated with the estimation of oil reserves or rates of oil supply. This appears to be an area where a range of methods is used and some consistency may be appreciated. Models of oil supply could be used to work with estimates on the future impact on economies.

14 PAPER 8 – SPECIAL REPORT ON RENEWABLE ENERGY AND CLIMATE CHANGE MITIGATION

Citation of paper: Coordinating Authors: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K.. Matschoss, P., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., [eds.] (2011). *IPCC, 2011: Summary for Policymakers in Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge UK and New York, NY, USA.

Location: http://srren.ipcc-wg3.de/report/IPCC_SRREN_SPM

14.1 *Abstract*

14.1.1 The objective of the document is to present an assessment of the literature on the scientific, technological, environmental, economic and social aspects of the contribution of six renewable energy technologies (bio-energy, direct solar energy, geothermal energy, hydropower, ocean energy, wind energy) to the mitigation of climate change.

14.1.2 The report provides an overview of the current status of renewable energy technology (advancement and deployment). In recent years, deployment has been found to have been increasing rapidly despite global financial challenges thanks to various types of government policies, the declining cost of many renewable technologies, changes in the prices of fossil fuels and an increase of energy demand amongst other variable factors.

14.1.3 Some renewable energy technologies are found to be broadly competitive with current market energy prices. Many others can provide competitive energy services in certain circumstances, for example, in regions with favourable resource conditions or that lack the infrastructure for other low-cost energy supplies. In most regions of the world, policy measures are still required to ensure rapid deployment of many renewable energy sources. However, overall, the cost of most renewable technologies has declined and additional expected technical advances would result in further cost reductions.

14.1.4 In order to establish renewable energy mitigation potential, a review of 164 scenarios from 16 different large-scale integrated models is conducted. The review found that for any given long-term GHG concentration goal, the scenarios exhibit a wide range of renewable energy deployment levels. In scenarios that stabilise the atmospheric carbon dioxide (CO_2) concentration at a level of less than 440 ppm, the median renewable energy deployment levels are 139 EJ/yr[25] in 2030 and 248 EJ/yr in 2050, with the highest levels reaching 252 EJ/yr in 2030 and up to 428 EJ/yr in 2050. This range is a result of differences in assumptions about factors such as:

- developments in renewable energy technologies and their associated resource bases and costs;
- comparative attractiveness of competing mitigation options (e.g. end-use energy efficiency, nuclear energy and fossil energy with carbon capture and storage (CCS));
- fundamental drivers of energy services demand (including future population and economic growth);
- the ability to integrate variable renewable energy sources into power grids;
- fossil fuel resources;
- specific policy approaches to mitigation; and
- emissions pathways towards long-term goals (e.g. overshoot versus stabilisation).

14.1.5 However, despite potential variations, the scenarios indicate that, all else being equal, more ambitious mitigation generally leads to greater deployment of renewable energy.

14.1.6 The scenarios do not indicate an obvious single dominant renewable technology at a global level. However, although the contribution of renewable energy technologies varies across scenarios, modern biomass, wind and direct solar commonly make up the largest contributions to the global energy system. All scenarios assessed confirmed that technical potential is not the limiting factor for the deployment of renewables globally. In order to estimate investment needs (in the power generation sector only), four illustrative scenarios are analysed in detail. The needs range from $\$USD_{2005}$ 1,360 to 5,100 billion for the decade 2011 to 2020, and from $\$USD_{2005}$ 1,490 to 7,180 billion for the decade 2021 to 2030, for the whole world in the power generation sector only. The lower values refer to the IEA (2009) World Energy Outlook reference scenarios and the higher

[25] EJ/yr (Exajoule per year) 1 Exajoule = 1018 joules = 23.88 million tonnes of oil equivalent (Mtoe).

ones, to a scenario that seeks to stabilise atmospheric CO_2 concentrations at 450 ppm. The annual averages of these investment needs are all smaller than 1% of the world's gross domestic product (GDP). The higher values of the annual averages of the renewable energy power sector investment approximately correspond to a five-fold increase in the current global investments in this field.

14.1.7 Government policies play a crucial role in accelerating the deployment of renewable energy technologies. The primary drivers have been energy access and social and economic development in most developing countries and secure energy supply and environmental concerns in developed countries. Renewable-energy-specific policies for research, development, demonstration and deployment help to level the playing field. Policies include regulations such as feed-in-tariffs, quotas, priority grid access, building mandates, biofuel blending requirements, and bioenergy sustainability criteria. Other policy categories are fiscal incentives such as tax policies and direct government payments such as rebates and grants; and public finance mechanisms such as loans and guarantees. Wider policies aimed at reducing GHG emissions such as carbon pricing mechanisms may also support renewables. However, there is no one-size-fits-all approach for effective renewable energy policy.

14.2 *Actuarial implications and importance*

14.2.1 162 of the 164 quantitative scenarios in IPCC (2011) are taken from Krey and Clarke (2011); the remaining two are from IEA (2009) and Teske et al. (2010). The actuarial profession can contribute to them by improving and refining the holistic simulations (e.g. IPCC (2011) acknowledges that the difference between bottom-up and top-down simulation is not so well defined anymore; this means that more simulations studies are being conducted using holistic approaches and that there is opportunity to improve holistic simulation approaches.

14.2.2 The four specific scenarios in IPCC (2011) are taken from: IEA (2009), Luderer et al. (2009), Calvin et al (2009) and Teske et al. (2010). Within IPCC (2011) each study is different and worth looking at. Still, most models do not look at extreme case scenarios or contingent scenarios. This could be an area where actuaries might have a useful contribution.

14.2.3 There is an opportunity for actuaries to define a risk (e.g. like climate change and its impact on pension funds) to model using dynamic-recursive models. Only a couple of studies in IPCC (2011) consider this approach.

14.3 *Actuarial critique*

14.3.1 Assessments of the costs of future paths of renewable energy deployment and mitigation have to consider the whole range of other costs, including external costs, co-benefits and risks.

14.4 *Source of further actuarial study*

14.4.1 Within the 164 scenarios, there is an opportunity for multivariate data analysis. For example: a construct that takes into account the implementation of one or all the six different technologies and their relation to different sources technological risk, like political support and/or accession (Calvin et al. 2009), to mathematically support the simulation studies.

14.4.2 There is opportunity to contribute and to extend specific scenarios using actuarial models that consider contingencies and risks.

C. CURRENT STATUS OF CLIMATE SCIENCE

15 PAPER 9 – PALEO-CLIMATE IMPLICATIONS FOR HUMAN-MADE CLIMATE CHANGE

Citation of paper: Hansen, J. and Sato, M., (2011). *Paleo-climate Implications for Human-Made Climate Change*. NASA Goddard Institute for Space Studies and Columbia University Earth Institute, New York

Location: http://www.columbia.edu/~jeh1/mailings/2011/20110118_MilankovicPaper.pdf

15.1 *Abstract*

15.1.1 For a number of years James Hansen has argued vehemently that continued global warming will result in far greater impacts than many climate models have projected, and in this paper he continues the theme by arguing that palaeoclimatology (the study of past climate change) gives a clearer view of the rate of Earth System responses to climate change, such as sea level rise, than current Global Climate Models. In this paper, Hansen and Sato use past climate change and the changing insolation patterns produced by orbital cycles that drove this (so-called 'Milankovitch oscillations') to assess the implications for the global climate of continued anthropogenic-driven energy imbalance in the atmosphere. They argue that understanding the temperature responses to past Milankovitch climate oscillations allows researchers to develop a more precise evaluation of equilibrium climate sensitivity than current assessments using computer modelling.

15.1.2 The authors start by examining the period of time over the past 65.5 million years (Ma), known as the Cenozoic era. In the early Cenozoic, Earth was warm enough for no ice sheets to exist and for global sea levels to be around 75m higher than present. A long-term global cooling trend started around 50 Ma ago and by around 34 Ma ago large ice sheets had developed in Antarctica. Further cooling from 15 Ma allowed Northern Hemisphere ice sheets to develop, and these global ice masses provided the albedo[26] feedback and the conditions for CO_2 feedbacks to begin to amplify temperature responses to changes in orbital forcing. The authors estimate the contribution of various forcings during the Cenozoic (including solar luminosity, volcanic activity the role of plate tectonics in sequestering CO_2 and changes in the location of continental land masses over the time period) and conclude that CO_2 was the dominant climate forcing element at this time.

15.1.3 They use the present glacial-interglacial cycle to determine likely climate sensitivity (usually defined as the equilibrium response of global mean surface temperature to a doubling of atmospheric CO_2 concentrations above pre-industrial levels). Hansen and Sato then argue that equilibrium was achieved during the last ice age and during at least the early to mid-Holocene after the melting of the mid-latitude ice sheets and before the onset of substantial human emissions of greenhouse gases. Their estimate of the co-relationship between temperature rise and climate forcing at the tropopause is similar to their previous estimates of 0.75 °C per W/m^{-2} change in the forcing, consistent with a current estimated climate sensitivity of around 3°C. This empirical climate sensitivity incorporates all fast feedbacks to the initial temperature change, including changes in water vapour, clouds, atmospheric aerosols, sea ice extent and biochemical processes.

15.1.4 The authors add considerable information on the methodologies available to palaeoclimatologists by discussing the techniques used to reconstruct past temperature change. They make the claim, that Hansen has made before, that understanding the magnitude and drivers of

[26] See glossary of terms on page 76.

past temperature change can provide crucial information for assessing the likely success of future policy goals.

15.1.5 It is clear that the palaeoclimate record shows us that our current climate change policies are not being driven by the latest science. Hansen and Sato discuss the concept of 'dangerous climate change' (although without defining this) and argue that the commonly held assessment of 2°C relative to pre-industrial times (and 1.3°C relative to 2000) which was adopted by EU policymakers is unlikely to prevent catastrophic impacts. The paper supports this assertion by making some interesting assessments of the warmth of early and late interglacials during the Quaternary, and arguing that later interglacials were warm enough for rapid melting of the ice shelves around the Greenland and Antarctic ice sheets and on the surfaces of the ice sheets themselves. This probably contributed to rapid albedo-driven local temperature change in the vicinity of the ice sheets. While this process probably did not occur during the relatively cool Holocene, the authors argue that we are currently close to initiating such an 'albedo flip' mechanism and that this would drive more rapid sea level rise than has been expected. This is based upon an (uncontroversial) view of polar temperature change being amplified at twice that of the mid- and low-latitudes.

15.1.6 Hansen and Sato estimate that global temperatures in 2000 reached those occurring at the peak of the Holocene and were well within the peak temperatures of previous interglacials such as the Eemian. They also conclude that present temperatures are within 1-2 °C of the peak of the Pliocene, when sea levels were around 25m higher than present and with atmospheric CO_2 concentrations lower than today at about 380ppm.

15.1.7 Hansen and Sato argue that the IPCC AR4 sea level projections for the end of the century make the likely incorrect assumption that sea level rise is likely to be linear in response to increasing global temperatures. Their alternative view is that we should consider a non-linear response, especially given the fact that much of the West Antarctic Ice Sheet (and parts of the East Antarctic Ice Sheet) are grounded below sea level, making them highly vulnerable to breaking up once buttressing ice shelves are melted and sea level rise has reduced the effectiveness of topographic pinning points and grounding lines on outlet glacier stability. They argue, with a plausible doubling time of ice sheet mass loss of 5-6 years, the possibility remains that multi-meter sea level rise could occur by 2100. They conclude that adopting a Business As Usual emissions scenario (which best describes our present trajectory), global temperatures would rise by 3-6 °C by 2100, and they argue that in this case "*multi-meter sea level rise on the century time scale are not only possible, but almost dead certain*".

15.2 *Actuarial implications and importance*

16.2.1 This is an important paper which reinforces the claim, that Hansen has made before, that understanding the magnitude and drivers of past temperature change can provide crucial information for assessing the likely success of future policy goals. This is a valuable perspective and one that is now beginning to gain considerable currency. What is of great importance is the clear way in which it spells out the ways in which palaeoclimate reconstruction can provide valuable insight into future climate change and support the policy implications of this.

15.3 *Actuarial critique*

15.3.1 The paper could have made more of the importance of three issues: first, the threat posed by the impact of sea level rise. The IPCC estimated that global average sea level rise by 2100 would be in the range of 18-59cm. However, this figure did not include an assessment of the contribution to sea level by melting ice sheets on the grounds that our understanding of the physics of ice sheet disintegration was low at the time. Subsequent research has improved our knowledge of ice sheet grounding processes, subglacial hydrology and connectivity and calving and we can suggest that the IPCC projections are likely to be grossly underestimating future rise; as a result of the IPCC's projections, most researchers have put a limit of sea level rise by the end of the century at around 1.5-2.0m. Second, the impact of sea level rise will be highly variable. Already the sea surface varies by tens of metres over the surface of the Earth and the shifts in ocean currents, salinity and gravitational effects predicted for the future will magnify these variations. This means that vulnerability to sea level rise will be highly regional and this is not reflected in most actuarial analyses. Third, the authors might have shown how the dynamic nature of past climate change is rarely successfully modelled by the present generation of Global Climate Models. Since these are used to develop climate policy and risk management evaluations, this is a clear failing of climate models.

16 Paper 10 – Climate Stabilisation Targets: Emissions, Concentrations & Impacts

Citation of paper: Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentrations, National Research Council (2011) *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*, The National Academies Press, Washington D. C., USA.

Location: http://www.nap.edu/catalog.php?record_id=12877

16.1 *Abstract*

16.1.1 This is a report by the Committee on Stabilization Targets for Atmospheric Greenhouse Gas Concentration, at the National Research Council of the National Academy of Sciences (NAS). It was published in April 2011, and is therefore significantly more up to date than the last report from the Intergovernmental Panel on Climate Change (IPCC), whose 4th Assessment Report (AR4) was published in 2007.

16.1.2 For a very brief overview of the contents, the first section of the synopsis is reproduced below:

> "*Emissions of carbon dioxide from the burning of fossil fuels have ushered in a new epoch where human activities will largely determine the evolution of Earth's climate. Because carbon dioxide in the atmosphere is long lived, it can effectively lock Earth and future generations into a range of impacts, some of which could become very severe. Therefore, emissions reductions choices made today matter in determining impacts experienced not just over the next few decades, but in the coming centuries and millennia. ....*
>
> *Since the beginning of the industrial revolution, concentrations of greenhouse gases from human activities have risen substantially. Evidence now shows that the increases in these gases very likely (>90% chance) account for most of Earth's warming over the past 50 years. Carbon dioxide is the greenhouse gas produced in the largest quantities, accounting for more than half of the current impact on Earth's climate. Its atmospheric concentration has risen about 35% since 1750 and is now at about 390 ppmv, the highest level in at least 800,000 years."*

16.1.3 The report has the following six sections:

1. Introduction
2. Emissions, concentrations and related factors
3. Global mean temperature responses
4. Physical climate change in the twenty-first century
5. Impacts in the next few decades and coming centuries
6. Beyond the next few centuries

16.1.4 The layout of this NAS report sets out the current state of science about the response of the climate over various timescales. This is clear from the titles of chapters 4, 5 and 6.

16.1.5 Rather than review the entire 200 page report in a very short space, this review focuses on one key question. In another paper reviewed in this Literature Review (*Paper 20*), the economist Martin Weitzman argued that the "tail risk" of catastrophic climate change should be a much larger factor in the policy response. Tail risk is the risk that the actual sensitivity of the climate to greenhouse gas is within the extreme end, or tail, of the probability distribution of possibilities. In this review we look into the state of the art climate science to look for evidence of the tail risk from extreme climate change. The rest of this review is organised with that objective in mind.

16.1.6 The specific aspects of climate change covered in this review are the persistence of carbon dioxide emissions in the atmosphere, the uncertainty in the current amount of radiative forcing (i.e. the net energy input that is warming the Earth), and the uncertainty in the long-term response of the climate.

Overview of Timescales and Climate Sensitivity

16.1.7 The report uses three different measures for Climate Sensitivity. These are referred to as "Climate Sensitivity" without further qualifiers, "Transient Climate Response" (not relevant for this review) and "Earth System Sensitivity". To understand the likely long term response of the climate it is important to understand the difference between these measures. For the long-term response of the climate it is the Earth System Sensitivity that is of most interest.

16.1.8 **Climate Sensitivity**: The climate system has many feedback processes, both positive and negative; positive feedback, meaning self-reinforcing, negative, meaning self-cancelling.

16.1.9 Feedbacks operate over various timescales. Climate sensitivity is a parameter that estimates the equilibrium response to changes in CO_2 including relatively fast feedbacks, primarily water vapour, clouds, sea ice, and snow cover. The equilibration of the climate with these fast feedbacks is estimated require multiple centuries to a millennium. The term "equilibrium" as used in chapter 3 of the report, always refers to the equilibrium response incorporating only these feedbacks. Climate sensitivity refers to the measure that was reported by the IPCC in AR4.

16.1.10 **Earth System Sensitivity:** The third kind of climate sensitivity is called Earth System Sensitivity (ESS). Recent developments in climate science have shown that anthropogenic CO_2 is likely to affect the climate over millennia. ESS is a measure of the long term response of the climate incorporating all feedback processes, including slower feedbacks that can set in over millennial timescales and any additional feedback processes (either positive or negative) which have not yet been discovered.

16.1.11 Long-term feedbacks include changes in the carbon cycle causing release of stored carbon to the atmosphere, and partial or total deglaciation of Greenland and Antarctica. Both of these examples are positive feedbacks, which would cause additional warming.

The Persistence of Carbon Dioxide Emissions in the Atmosphere

16.1.12 In the just the last few years the scientific literature has prompted the new understanding that anthropogenic emissions must approach zero eventually if atmospheric carbon dioxide concentrations are to be stabilized.

The Uncertainty in the Current Amount of Radiative Forcing

16.1.13 Radiative forcing (RF) refers to the radiative flux change; in other words the net energy flow to the Earth caused by changes to greenhouse gases in the atmosphere (and other changes). There was a high degree of uncertainty about the net RF estimated in AR4. This report does not resolve that uncertainty.

The Uncertainty in the Long-Term Response of the Climate and "tail risk" from climate change

16.1.14 In this section, we point out a number of relevant passages from the report, with page references. These sections illustrate the uncertainty in the response of the climate and the potential for feedback processes to drive warming higher.

Change in the carbon cycle (p.79)

16.1.15 Rising temperatures might cause land ecosystems to lose carbon to the atmosphere. Large effects could occur if future climates lead to more fires, or widespread replacement of forests with grasslands.

Uncertainty in the response of clouds (p. 90)

16.1.16 Current climate models have deficiencies in their simulation of clouds, which causes uncertainty in the sensitivity of the climate.

Loss of arctic sea ice might cause permafrost melt in the arctic (p. 142)

16.1.17 Loss of ice cover is a positive feedback, because ice reflects most of the radiation that falls on it, whereas open water absorbs most of it. Climate simulations indicate that rapid loss of arctic ice may cause permafrost melt, and this warming may penetrate up to 1,500km inland.

Release of carbon stores (p. 222)

16.1.18 In a warmer world, man-made releases of carbon dioxide from burning fossil fuel could be augmented due to release of gases from carbon reservoirs. For example, methane from methane hydrates from permafrost and under the deep ocean. Also carbon dioxide may be released from warming peat and soils. Some of these sources may be very large.

Field studies have already found remarkably large local emissions of methane from melting permafrost at some arctic sites.

Unexplained warming during the Palaeocene-Eocene Thermal Maximum (PETM) event (p. 225)

16.1.19 The PETM occurred around 55 million years ago, when an organic carbon reservoir began to oxidize rapidly and became a source of additional atmospheric carbon dioxide, which caused rapid warming of the climate. The processes that led to the PETM carbon release are not understood. So the risk that anthropogenic global warming could trigger a similar catastrophic release cannot yet be quantified, except to say that the risk is real.

16.2 *Actuarial implications and importance*

16.2.1 The implications of climate change for the actuarial profession can be divided into two general areas. The first is the potential impact upon areas of actuarial work. The second is the issue of how the actuarial skill-set might be suitable to help in the evaluation of the risk from climate change, both at the level of policymakers and with the public understanding of climate change.

16.2.2 Actuaries working in general insurance have known for some time that climate change is a critically important impact upon premium rates and the risk from natural catastrophes. For actuaries concerned with investment returns, the importance to actuarial advice may come less from the direct effect of climate change and more from regulation that arises as governments recognise the seriousness of the problem. It would be a mistake to underestimate the potential change arising from carbon regulation as the world awakens to the danger of climate change. Huge shifts in investment patterns and valuations of companies may possible, particularly for those companies either involved in fossil fuel extraction or heavily dependent on fossil fuel use. This is particularly the case as understanding grows that in order to stabilise the climate it is necessary to completely decarbonise the economy. As this knowledge becomes more widely known, some types of technology that cut carbon, but are not completely carbon neutral, may not make sense.

16.2.3 With regard to the public understanding of science and the policy response, we should be aware of worrying trends in the world today. For example, in the US, the Republican Party has for the most part turned away from science to the point where it is difficult to be a Republican Party candidate and admit to a belief in anthropogenic climate change.

16.3 *Actuarial critique*

16.3.1 This NAS report is an extremely useful summary of the state of climate science as at the beginning of 2011. At just over 200 pages, the report is also very much shorter than AR4 therefore much more manageable[27]. We would recommend the report to anyone interested in learning about state-of-the-art climate science.

16.3.2 A very large amount has been learned about climate change over the last few decades and climate science has continued to develop rapidly in recent years. There are many things we can say with a high degree of confidence. Such as, for example, the world is warming and that changes to the atmosphere caused by mankind are responsible for that warming.

[27] There is also a shorter, 35-page summary report called “Warming World: Impacts By Degree”. This review is of the main report.

16.3.3 This review focuses on areas where climate science appears to be in a process of change, as new aspects of the climate system come to light. It is important to remember that as science develops, new science builds upon the old and estimates change. The fact that scientific estimates change over time is the normal operation of science, in fact we should be more concerned if there was no change.

16.3.4 We return to the key question – can we get a better understanding of the magnitude of tail risk from climate change by analysing this report? In his paper [*paper 20*] Weitzman uses a time horizon of around two centuries. One of the most important questions that must be answered in looking at tail risk over this time horizon is, whether the processes identified in chapter 6, said to be "beyond the next few centuries", might instead operate within the next two centuries?

16.3.5 In light of the contents of section 17.1.18 to 17.1.29 we suggest that there is a very real risk that feedback processes, considered to be longer-term and operating on a millennial timescale, might instead progress faster and operate instead on a timescale within the next two centuries. To quote just one example: In paragraph 17.1.26 field studies are mentioned which show that methane release from melting permafrost is already increasing today.

16.3.6 We point to the review of Hansen's paper, also in this Literature Review. We think that the science identified in this NAS report lends credibility to the risk that Hansen has identified.

16.3.7 The report specifically does not cover either geoengineering or reforestation or other methods of sequestering carbon dioxide from the atmosphere. We understand that a report of this nature cannot cover every aspect of climate change science and policy, a line has to be drawn somewhere. However, if the sensitivity of the climate is in reality towards the high end of probability distribution, then both geoengineering (to cut warming in the short term) and sequestering carbon from the atmosphere (to stabilise climate in the long term) may well prove to be necessary.

16.4 *Source of further actuarial study*

16.4.1 On questions of modelling, including estimations of uncertainty and limitations of models, the actuarial skill-set might find a useful application.

D. ECONOMIC RESPONSES

17 PAPER 11 – PROSPERITY WITHOUT GROWTH

Citation of paper: Jackson, T. (2009) *Prosperity Without Growth? Economics for a Finite Planet*, Routledge, London, UK.

Location: www.earthscan.co.uk/pwg

17.1 *Abstract*

17.1.1 This book was published in 2009 as an expanded, revised and updated version of the report by the Sustainable Development Commission, which was touched upon very briefly in the 2010 edition of this Review. The book is over 200 pages long, therefore only a few key concepts are covered in this review.

17.1.2 The core message of the report can be summed up by this extract from the foreword of the original Sustainable Development Commission report by the author, Professor Tim Jackson:

> "*Every society clings to a myth by which it lives. Ours is the myth of economic growth. For the last five decades the pursuit of growth has been the single most important policy goal across the world. The global economy is almost five times the size it was half a century ago. If it continues to grow at the same rate the economy will be 80 times that size by the year 2100*.
>
> *This extraordinary ramping up of global economic activity has no historical precedent. It's totally at odds with our scientific knowledge of the finite resource base and the fragile ecology on which we depend for survival*."

17.1.3 Jackson points out that economic growth has delivered its benefits very unequally to the global population, with a fifth of the world's population earning just 2% of global income. Also, as the world economy expands, carbon emissions rise and scarce resources such as oil are used at a faster rate. Since these impacts are already unsustainable, the report challenges the assumption of continued economic expansion in rich countries.

After the forewords, the book consists of 12 chapters. Below some of the key section headings are shown, with very short summaries of their content.

- **Prosperity Lost**. Jackson highlights the environmental limits of our economic growth system. He concludes that "*Questioning growth is deemed to be the act of lunatics, idealists and revolutionaries. But question it we must*."

- **The Age of Irresponsibility** refers to the financial crisis of 2008. Continued expansion of credit was seen as essential to stimulate consumption growth. Therefore the drive for faster growth made the economic system more unstable.

- **Redefining Prosperity**. Jackson acknowledges it is not possible to be prosperous without having the material necessities of life. However, there have been many studies which show that above a certain level of wealth, the benefits of additional wealth tail off. Graphs which show two examples are shown below:

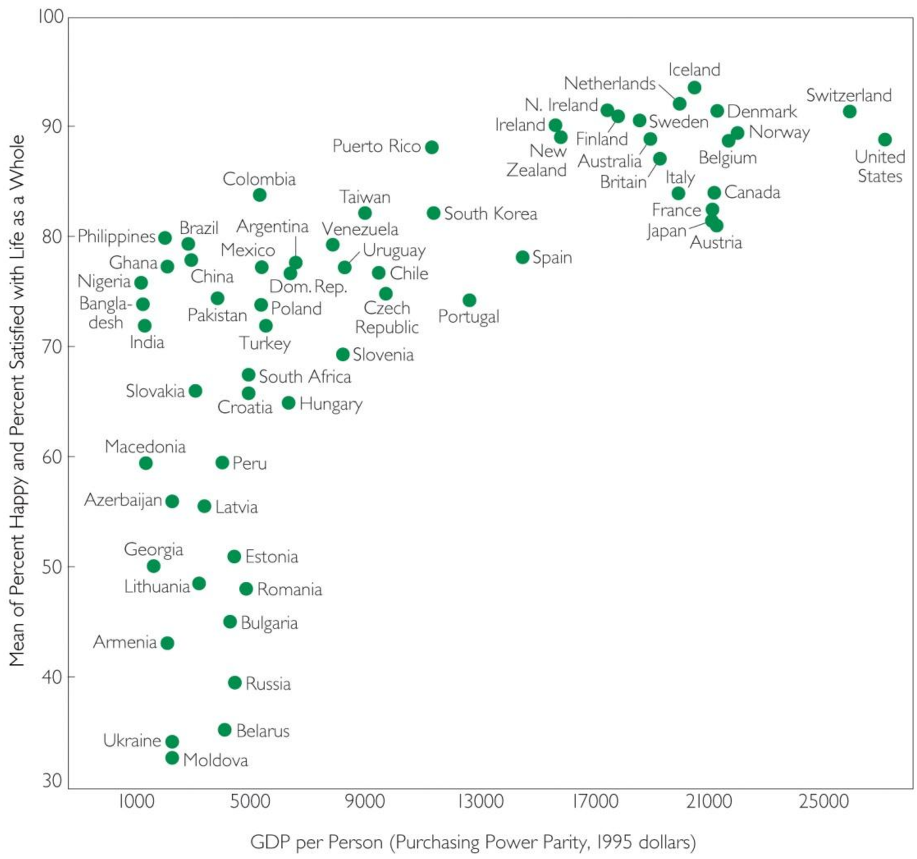

Fig 3: Happiness and average annual income[28]

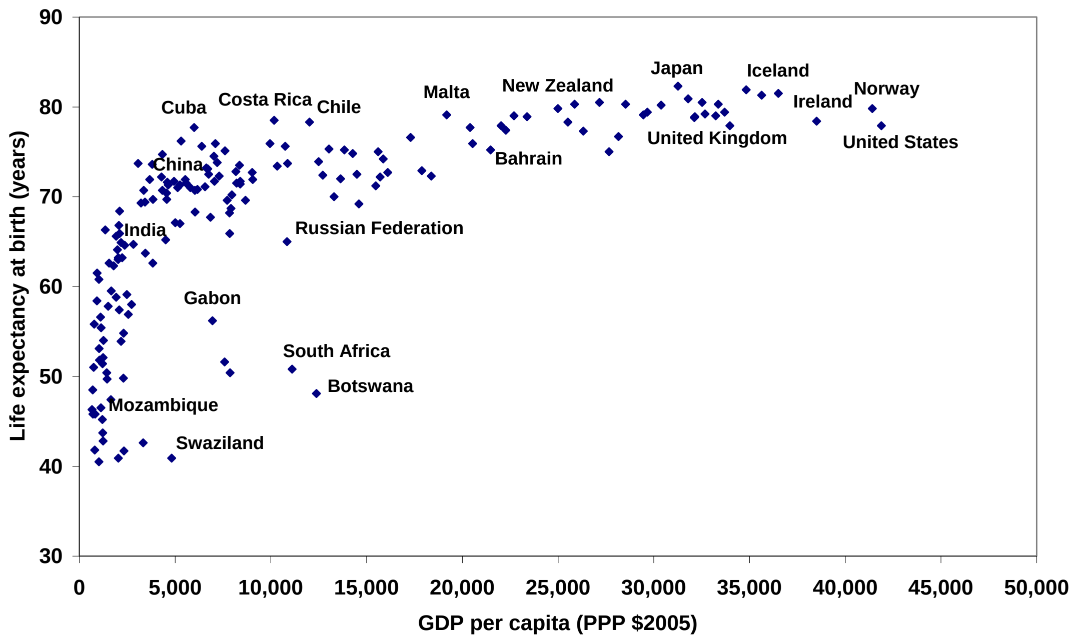

Fig 4: Life expectancy at birth vs average annual income

[28] Figs. 3,4,5,6 from Jackson, T. (2009) *Prosperity Without Growth? Economics for a Finite Planet*, Routledge, London, UK.

- **The Dilemma of Growth**. Until now, growth has been the default mechanism that prevents economic collapse. This is because rising wealth has been driven by increased labour productivity, caused by improvements in technology. Better labour productivity means that fewer people are needed to produce the same amount of goods. As long as the economy expands fast enough to consume the additional goods this is ok. However, if the economy does not grow then unemployment increases. As people lose their jobs there is less money in the economy, which then goes into a downward spiral. Hence, under this system, growth is necessary just to prevent collapse.

- **The Myth of Decoupling**. For the impact of the economy to decrease, there has to be absolute decoupling between the physical impacts of the economy and GDP. In other words, the total amount of physical input and pollution has to decrease. This has not been the case to date, which is illustrated by the following graphs:

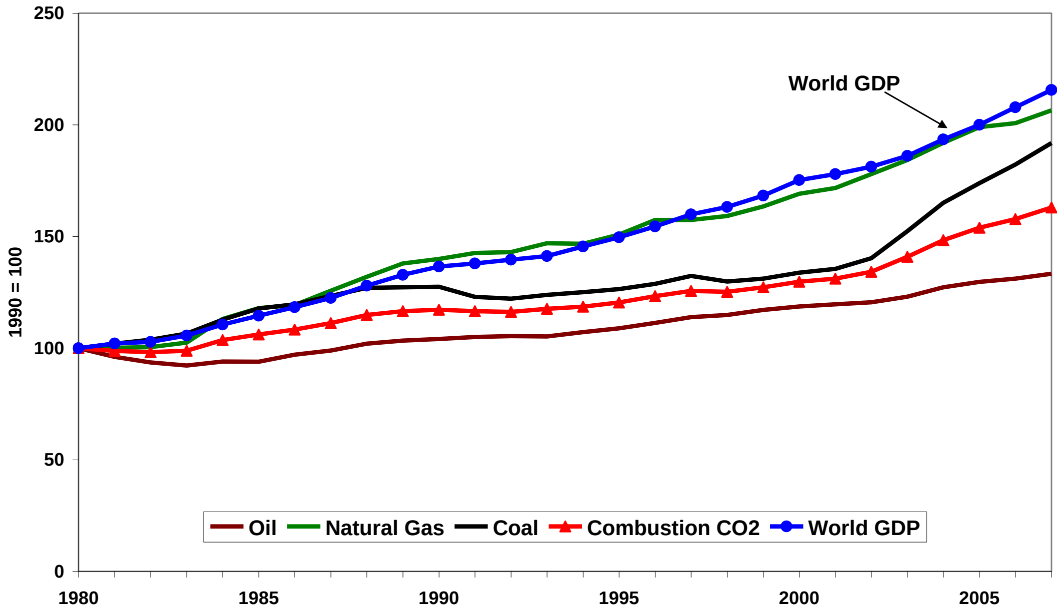

Fig 5: Trends in fossil fuel consumption and related CO_2: 1980-2007

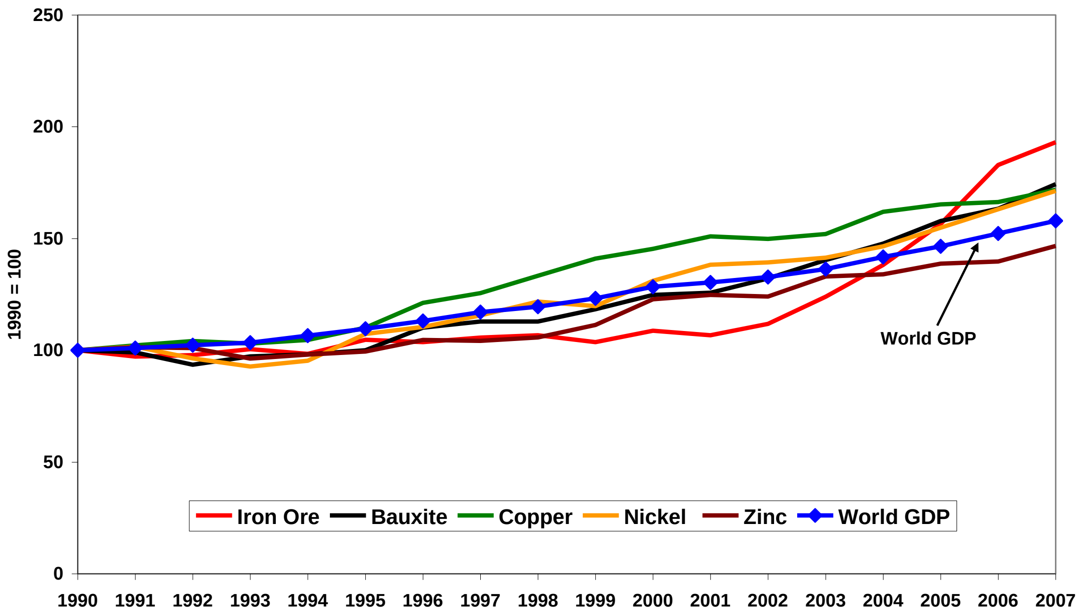

Fig 6: Global trends in primary metal extraction: 1990-2007

- **The 'Iron Cage' of Consumerism**. Jackson suggests that in order to achieve deep cuts in resource use and emissions, the structure of modern market economies must be confronted, and social norms, such as that of competitive consumption, must be changed.

- **Keynesianism and the Green New Deal.** Green stimulus packages are based on the default assumption of returning the economy to a condition of consumption growth. But for an ecologically constrained world, Jackson stresses that a different kind of economic model is needed.

- **Ecological Macroeconomics**. The economists John Stuart Mill and John Maynard Keynes both foresaw a time when growth would have to stop. In more recent times, ecological economists such as Herman Daly for example, have outlined an alternative, steady-state economic system that would function sustainably.

- **Flourishing – within Limits** Jackson believes that if structural change can be achieved to reduce consumption, then the advantages in terms of prosperity are likely to be substantial. A less materialistic society will enhance life satisfaction. A less growth-driven economy will improve people's work-life balance.

- **Governance for Prosperity** Jackson suggests that Government faces conflicting demands. For as long as macro-economic stability depends on economic growth, government will have an incentive to promote materialism over social, ecological and long-term interests. Jackson argues that releasing the macro-economy from a structural requirement for growth will free government to protect long-term interests.

- **The Transition to a Sustainable Economy**. Jackson suggests 12 steps that would move the economy to a sustainable path. These are divided into 3 sections comprising 1) Establishing the limits; 2) Fixing the economic model; and 3) Changing the social logic.

- **A Lasting Prosperity**. Jackson's final message is that for the advanced economies of the Western world, prosperity without growth is no longer a utopian dream. It is a financial and ecological necessity.

17.2 *Actuarial implications and importance*

17.2.1 Assumptions about future economic growth underlie all financial asset prices and interest rates. To take just one example; that of government bond yields, which underpin the "risk-free" rate of interest. It is a simplification, but it is fair to say that in the long-term, governments can only afford to pay interest on their debt because of economic growth. Without growth long-term interest rates would be greatly affected, in fact the level of debt held by rich-nation governments could not be sustained. Therefore assumptions of future economic growth rates are of the utmost importance to actuarial work.

17.3 *Actuarial critique*

17.3.1 At the outset we should acknowledge that economic growth in the past has given us the high standard of living we enjoy in rich countries today. Good education, low mortality rates, sanitation, public goods such as roads and railways, all of these are possible because of the benefits of a large GDP.

17.3.2 Economic growth continues today to raise standards of living in developing countries, particularly in rapidly growing nations such as China and India. However, the fairness argument raised by Jackson has some force. If we wish to lift the world's poor out of poverty, then a system which grows the economies of both rich and poor nations is a very inefficient way of doing this. In a world with no constraints upon growth this would not be so important, as eventually faster growing poor nations would catch up with richer nations. But if growth is limited, it seems unjust that a large amount of the benefits should go to the citizens of rich nations.

17.3.3 Perhaps the parts of the growth debate that will resonate the most with the actuarial profession are those related to the risk from growth, and the sheer plausibility, or otherwise, of its continuing in the coming decades. In his simple mathematical projection, Jackson projects the long-term growth rate of the global economy at slightly more than 3% p.a. (this would be an uncontroversial assumption for long-term real economic growth in conventional analysis). If growth continued at this rate until the end of the 21st century, the global economy would grow more than 15 times as large as it is today. Bearing in mind the resource and environmental constraints identified in the report and in the rest of this Literature Review[29], Jackson has a strong case that continuation of the past rate of growth is implausible and attempting to try to achieve it is highly risky.

17.3.4 The vast majority of conventional analyses look for solutions to sustainability issues within a system of consistently increasing global consumption. Such solutions are based upon notions such as "green growth" and dematerialisation of production. This is a problem from a risk management point of view, because what happens if it turns out to be simply impossible to grow the economy and simultaneously reach a sustainable outcome? Should we then give up, and decide that sustainability is not possible for humanity? Or would it be sensible to be open to the possibility that a Plan B, involving no growth, might be necessary?

[29] For example, see the review of the IMF chapter on the potential impact of peak oil on global economic growth.

17.3.5 The risk-based way of looking at the problem is similarly an obvious point of interest for the actuarial profession. It is legitimate to ask, for the citizens of rich nations, have we come to a point where the risks from additional growth outweigh the benefits?

17.3.6 Coming to the plausibility argument, we can look at parallels with conventional actuarial work. It is often the case that the actuary understands the essential aspects of the system upon which he or she is being asked to report. For example, that system might be a pension fund (looking at funding adequacy, bearing in mind changes in mortality) or a general insurance company (reserving for claims payments, bearing in mind trends in claims).

17.4 *Source of further actuarial study*

17.4.1 The Institute & Faculty of Actuaries has commissioned research into environmental and resource constraints which might limit economic growth. The results of this research are expected to be published in 2012. We hope that this research will stimulate much wider discussion and investigation of the physical limits to economic growth, both within and outside the actuarial profession.

18 PAPER 12 – A BLUEPRINT FOR A SAFER PLANET

Citation of paper: Stern, N. (2009), *A Blueprint for a Safer Planet: How to Manage Climate Change and Create a New Era of Progress and Prosperity*, Bodley Head: London, UK

Location: http://www.rbooks.co.uk/product.aspx?id=1847920373

18.1 *Abstract*

18.1.1 *A Blueprint for a Safer Planet* was written several years after the publication of the *Stern Review: The Economics of Climate Change* in 2006. The book provides Stern's views on how to structure a global deal in order to manage the risk of climate change.

18.1.2 The book was written before the 2009 Climate Change Summit in Copenhagen and has a sense of optimism. Stern recognises that the bulk of the action towards reducing greenhouse gases will come from the private sector, only if "*public actions and policies give the right signals and rewards for cutting greenhouse gases*." Stern argues that "*without a strong public policy framework in place, the incentives to act will fail to match the scale required*."

18.1.3 Stern emphasises that a global deal must be:

1. Effective – emissions should be cut back to the scale required otherwise future generations will live in a risky world;
2. Efficient – costs should be kept low to avoid wasting resources and to maintain support for action from all nations;
3. Equitable – in relation to abilities and responsibilities, taking into account both the origins and impact of climate change. If the deal is not equitable, poorer people could be treated unjustly and there is a risk of damaging the international coalition which is required for success.

18.1.4 Stern also notes that such a global deal is unprecedented and clearly there would be many challenges in establishing it.

18.1.5 One of the key arguments made in the book considers two kinds of mistake which could be made by human kind in respect of our actions in dealing with greenhouse gas emissions and the impacts of climate change:

1. We act on the scientific advice only to find that it turns out to be wrong; or
2. We act assuming the science is wrong, only to discover it turns out to be right.

18.1.6 Stern ask which of these two courses of action is more dangerous, concluding that although action (1) may have used up resources in reducing emissions that were not as risky as the science implied that could have been better used elsewhere, the world would have become more energy-efficient and have new technologies. However, under action (2), we may not realise the science is correct until it is too late. In this scenario, emissions will have continued to increase over that time, increasing the risk of dangerous climate change that is expensive or difficult to reverse.

18.1.7 Stern concludes this argument by stating:

> "*It would be grossly imprudent to act on the assumption that the science is wrong even if the probability of it being right were fairly low. And if we add to that the common-sense argument the reasonable assumption that there is a high probability that the science is right, then the argument for strong action is overwhelming.*"

18.2 *Actuarial implications and importance*

18.2.1 Stern believes that private sector firms are well placed to take action to reduce emissions and to encourage further reductions elsewhere. They can do this by:

1. Educating clients and employees on the business implications of climate change;
2. Developing products and policies to enable firms to take effective action.
3. Understanding that climate change can affect the bottom line as well as being an issue of corporate responsibility.

18.2.2 If we, as actuaries, understand the implications of climate change, we can educate our employers and our clients to allow them to understand the importance of this issue and to then educate other employees and colleagues. Actuaries can help guide the actions of many, which could create the stimulus for governments to make the necessary policy changes.

18.2.3 Stern states that "*at the heart of economic policy must be the recognition that the emission of greenhouse gases is a market failure*" in the sense that the cost of greenhouse gas emitting products and services (such as petrol or the extraction of aluminium with 'dirty energy') does not truly reflect the damage the emissions will cause on the future prospects of others. Actuaries need to consider this when making assumptions about long-term investment returns.

18.3 *Actuarial critique*

18.3.1 There is a detailed chapter on the potential impact of climate change on discount rates. In this chapter, Stern shares his view that the assumptions used in the Stern Review underestimated the costs of inaction. In particular, the assumptions for the growth of emissions and for the pace and severity of the impacts of climate change were too cautious.

18.3.2 When considering the impact of climate change on the discount rate to use when evaluating future projects, Stern notes that there is "*no financial or other market of any substance which reveals our choices as a group over a century or two*." This highlights the difficulty we have as actuaries in making a reasonable allowance for the impact of climate change on the future returns of investments.

19 Paper 13 – Towards Green Growth

Citation of paper: OECD (2011). *Towards Green Growth*. OECD Publishing.

Location: http://dx.doi.org/10.1787/9789264111318-en

19.1 *Abstract*

19.1.1 In June 2009, Ministers from 34 countries signed a Green Growth Declaration and endorsed a mandate for the OECD to develop a Green Growth Strategy. The *Towards Green Growth* framework, covering economic, environmental, social, technological and developmental areas, was published as a series of papers in May 2011. The overall objective was to "*provide a framework for how countries could achieve economic growth and development while, at the same time, combating climate change, preventing costly environmental degradation and the inefficient use of natural resources.*"

19.1.2 Green growth is defined as "*fostering economic growth and development, while ensuring natural assets continue to provide the resources and environmental services on which our well-being relies.*" This can be achieved through investment and innovation to drive sustainable growth and provide new economic opportunities. Productivity (making resources available to their highest value use), innovation, new markets, investor confidence (greater predictability and continuity with the way governments deal with major environmental issues) and stability (balanced macroeconomic conditions and reduced resource-price volatility) are sources of green growth.

19.1.3 A Business-As-Usual scenario would be "*unsustainable involving risks that could impose human costs and constraints on economic growth and development*." Such threats include water scarcity, resource bottlenecks (where the negative effects of the loss of natural capital exceeds the gains generated by economic activity), pollution, climate change and unrecoverable biodiversity loss.

19.1.4 The paper notes that changes in consumer habits, technology and infrastructure will be a long-term project. In particular, "*no government has all the technological, scientific, financial and other resources to implement green growth alone*." Therefore the challenges are global.

19.1.5 The paper argues that there are two broad sets of policies that are essential elements to a green growth strategy. The first is a "*broad framework of policies that mutually reinforce economic growth and the conservation of natural capital*". This includes fiscal and regulatory policies (such as tax and competition) which can help maximise efficient allocation of resources, if designed and executed well.

19.1.6 The second includes "*policies providing incentives to use natural resources efficiently and making pollution more expensive*." This includes public-private partnerships, public investment, tariffs, subsidies and taxes. Given the large-scale investments required in most countries to develop new forms of green infrastructure, this means that leveraging public and private financing is important.

19.1.7 For green innovation, green growth strategies need to address the issue that "*many environmental externalities are underpriced or not priced at all.*" A good example is that of carbon pricing which should be set at a level which encourages innovation to tackle climate change. However, the current level of carbon prices is too low to provide the necessary incentives.

19.2 *Actuarial implications and importance*

19.2.1 Low returns to green activities, innovation and investment may be due to the lack of rewards for avoiding pollution or unsustainable practices. This may be a result of either government failure and/or market failure. In addition, low economic returns from inertia and low social returns can lead to low returns to green growth. Actuaries may not have a direct role in setting policy and regulation in this space. However, there are areas in which actuaries can positively support green growth opportunities, such as investment and innovation.

19.2.2 As many of our clients are large institutional investors, an investment in 'green' venture capital, for example supporting R&D in low carbon technology, or in infrastructure, for example, in energy, transport, water or communications, can help new technologies and networks develop efficiently in order to lift economic growth and bring social and health benefits.

19.2.3 At present, there is a lack of innovation capability and a bias towards research and investment to incumbent technology. This may be due to insufficient demand for green innovation and lack of finance in such large and relatively risky projects. If there was demand from institutional investors to support new innovation via investment, asset managers may provide the required infrastructure to set up an investment fund which provides finance to the innovators and long term returns to investors.

19.3 *Actuarial critique*

19.3.1 The conclusions of the OECD's research are not new. However, *the Towards Green Growth* series of papers (particularly the Summary for Policy Makers) provide a succinct summary of the key actions that need to be taken in order to make global growth sustainable. Key to making the framework work is global collaboration and support, which may take some time to come to fruition.

19.4 *Source of further actuarial study*

19.4.1 The paper notes that environmental and resource productivity are "*rarely quantified in economic models and accounting frameworks*". This means that the efficient use of capital, as well as resource depletion and scarcity, are not realistically being captured by existing models. It is important to effectively model the decline in economic and environmental assets as this presents risks to growth. Actuaries have the necessary skill set to be able to contribute to this discussion.

20 Paper 14 – Decoupling Natural Resource Use & Environmental Impacts from Economic Growth

Citation of paper: Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E.U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A. (2011) *Decoupling Natural Resource Use and Environmental Impacts From Economic Growth: A Report of the Working Group on Decoupling to the International Resource Panel*. UNEP

Location: http://www.unep.org/resourcepanel/decoupling/files/pdf/Decoupling_Report

20.1 *Abstract*

20.1.1 Humankind has witnessed phenomenal economic and social development in the past century. However, there are increasing signs that it has come at a cost to the environment and to the availability of cheap resources. Despite progress, there is still great disparity between the rich and the poor.

20.1.2 The dilemma of expanding economic activities equitably while attempting to stabilize the rate of resource use and reduce environmental impacts poses an unprecedented challenge and opportunity to society.

20.1.3 In this report, the International Resource Panel (IRP) has sought to apply the concept of decoupling economic growth and human well-being from environmental impacts and resource use to address this challenge.

20.1.4 The report provides a solid statistical foundation for the concept of decoupling, clearly defining key terms and providing empirical evidence of escalating resource use. It shows that decoupling is already taking place to some extent, but is lagging far behind its potential.

20.1.5 'Decoupling' means using fewer resources per unit of economic output and reducing the environmental impact of any resources that are used or economic activities that are undertaken. The paper goes on to point out the difference between "relative" and "absolute" decoupling where "relative" means that the rate of increase in resource consumption is less than the rate of increase in economic output and "absolute" refers to an actual reduction in the resources consumed. It is important to note that "absolute" decoupling is recognised as being relatively rare.

20.1.6 Driven by scientific and technological advances, between 1900 and 2005 the extraction of construction materials has grown by a factor of 34, ores and minerals by a factor of 27, fossil fuels by a factor of 12, and biomass by a factor of 3.6. Overall, global resource extraction and use increased from around 7 billion tonnes in 1900 to 55 billion tonnes in 2000, with the main shift being from renewable biotic resources to non-renewable mineral ones. This expansion of consumption has not been equitably distributed, and it has had profound environmental impacts. Over-exploitation, climate change, pollution, land-use change, and loss of biodiversity have risen to the top of the list of major international concerns today.

20.1.7 In a section on scenarios for future global materials use, the report highlights the fact that we are facing a historic choice about how we use resources and scopes out the potential of innovation, rethinking economic growth and the role of cities in building more resource efficient economies. Four case studies at the country level – Germany and Japan on the one hand and China and South Africa on the other - demonstrate how policy makers are implementing decoupling strategies.

20.1.8 United Nations Environment Programme (UNEP) envisages that there will be a number of reports in this 'series'. This report focuses on material resources, namely fossil fuels, minerals, metals and biomass and will be complemented by parallel reports of the IRP on land and soil, water, metals, cities and technologies to mitigate GHG emissions. These future reports will contribute to the IRP's objective to build a better understanding of how to decouple environmental impacts from economic growth and improve human well-being.

20.2 *Actuarial implications and importance*

20.2.1 The paper does not assess the financial implications of their analysis and so has no direct actuarial implications.

20.2.2 However, there are likely to be some second order investment effects – but they may not be of sufficient importance to be measurable and directly attributable to decoupling. There is no quantitative work, for example, in linking decoupling with investment returns, investment risk, interest rates etc.

20.3 *Actuarial critique*

20.3.1 The paper starts from the premise that economic growth is desirable and deliverable in a sustainable way and then proceeds to analyse the historic relationships between their selected variables. Whilst this premise is politically valid, it would be far more interesting to actuaries if they examined the financial effect of the interruption of a key variable e.g. the effect of 'peak oil' on economic growth.

20.3.2 The concept of decoupling does not feature prominently in the mainstream actuarial literature. It is not clear what effect decoupling would have on the variables that are immediately important to the advice that actuaries provide e.g. economic growth, investment returns, inflation, interest rates etc.

21 Paper 15 – A Policy Framework For Peak Oil & Climate Change

Citation of paper: Fleming, D., Chamberlain, S. (2011), TEQs (Tradable Energy Quotas): *A Policy Framework for Peak Oil and Climate Change*, London: All-Party Parliamentary Group on Peak Oil, and The Lean Economy Connection.

Location: http://www.appgopo.org.uk/documents/TEQ_18Jan2011.pdf

21.1 *Abstract*

21.1.1 In the forward to this report, the chair of the All Party Parliamentary Group On Peak Oil and Gas ("APPGOPO") makes the point that many recent reports have warned of the need to prepare for the consequences of peak oil. In his view, Tradable Energy Quotas ("TEQs"), basically a system of energy rationing applied to the whole (national) economy, provide the fairest and most productive way to deal with the oil crisis and to simultaneously guarantee reductions in fossil fuel use to meet climate change targets.

21.1.2 At the heart of this TEQs model is the national Carbon Budget set, in the UK, by the Committee on Climate Change. The Budget states the volume of carbon emissions that will be permitted each year. The TEQs system then shares out this quantity, by the issue of units to individuals and into the market. On the first day of the scheme, one year's supply is issued; it is then topped-up each week (presumably as units are "consumed"), so that there is always a rolling year's supply of units in participants' accounts. Accounts are maintained by a Registrar.

21.1.3 Part of the issue is an unconditional and equal entitlement to all adults, issued directly into their TEQs accounts (around 40% of the units would be issued in this way, in line with the proportion of UK emissions that come from individuals and households). The remainder would be sold by tender, as part of the weekly auction that already takes place for the sale of Treasury Bills and Government debt. Banks and brokers obtain a supply of units on instructions from their clients, and distribute them to all non-household energy-users in the economy – to industry and services of all kinds, and to the Government itself. The tender provides revenue, which the Government uses to facilitate, in every way it can, the process of reducing dependence on fossil fuels.

21.1.4 When fuel or electrical energy is purchased, buyers pay for it as usual using money, but must also surrender units corresponding to the carbon content of their purchase. Individuals who use less than their regular entitlement of units can sell the surplus; those who need more can buy them on the market. The units are electronic.

21.1.5 A rating system evaluates fuels and electricity in terms of the carbon they contain and release. One TEQ unit is equivalent to one "carbon unit" – corresponding to the quantity of fuel or electrical energy that produces one kilogram of carbon dioxide over its lifecycle (not only from its final combustion, but also from the combustion of the other fuels used in bringing that fuel to market). The fact that the carbon content is known when energy or fuel is sold avoids the need for direct measurement of emissions from exhaust pipes, houses or factories.

21.1.6 The paper states that TEQs should ensure that the trajectory of reductions set by the Carbon Budget will actually be achieved. The quantity of fuel is determined by the Budget; the price adjusts around it. Price in the TEQs model is the free variable. However, it is contended that TEQs will tend to stabilise the price of energy in two ways. First, they prevent fuel (e.g. oil) being, in effect, distributed on the basis of an auction, with access being limited to the highest bidders (or the fastest movers). Secondly, the price of energy and the price of units will tend to move in opposite directions. If, or when, world oil prices reach very high levels, this will reduce the demand for oil, therefore reducing the demand for units and thus their price, so that the net price paid by consumers (oil + units) is more stable than the price of either oil or units alone.

21.1.7 Although the per capita entitlement is equal, the paper notes that this does not necessarily make it adequate for the individual's needs, but it brings into each individual's own life a direct encounter with the reality of diminishing access to energy. The depletion of oil and gas, and the scarcities and outages that will follow will make it necessary for the UK Government, in common with governments around the world, to install a rationing system. The paper makes the case that one system is needed to cover all users, both individuals and corporate.

21.1.8 TEQs are also designed to be capable of switching from carbon entitlements to energy entitlements at short notice. All accounts and systems will already be in place, and the changeover from reducing carbon emissions to sustaining fair access to the scarce fuel, while continuing the reduction in carbon emissions from fuels unaffected by the scarcity, will require only the activation of prepared settings to the system's programming.

21.1.9 The report concludes that we require a policy framework that guarantees emissions reductions while sustaining fair entitlements to fuel in conditions of scarcity. To do this, it must engage with and motivate the whole of society in the task of phasing-out our dependence on fossil fuels.

21.2 *Actuarial implications and importance*

21.2.1 This is an important paper which describes a possible mechanism which could have a key role in the economy in addressing energy constraints and carbon reduction targets. At present it is just a proposal but, in considering how it might work, a valuable insight can be obtained into the implications for the economy of these issues, whether or not it is actually introduced. These implications clearly include the impact on economic growth and resource allocation, both fundamental to long-term actuarial advice on funding liabilities and investment.

21.3 *Actuarial critique*

21.3.1 This is a radical proposal which would have far-reaching implications for the whole economy. It was originally put forward some years ago and has received some interest from the UK Government, in terms of research, but has not apparently yet been the subject of a full feasibility study. There has however been a range of academic studies which are listed in the bibliography. Linking TEQs to the Carbon Budget recommended by the Climate Change Committee provides a novel mechanism for engaging the whole population in the task which faces us.

21.3.2 In a short review it is not possible to adequately deal with the complexity of the issues raised. TEQs would certainly involve capital cost, administration, market upheavals and a major educational exercise. The opportunities for exploitation and fraud, and international implications, including the relationship with the EU Emissions Trading Scheme, would need to be carefully studied. On a detailed point, establishing the carbon rating of electricity would seem to be difficult, given the various methods of generation, and such issues as to whether to factor in the carbon cost of waste disposal for nuclear are also fraught with complexity.

21.3.3 A scheme like this would have major implications for investors and consumers. It is interesting in that it combines market forces with a structure designed to achieve climate change objectives. As rationing has only previously been introduced in times of war, it requires politicians to accept, and then convince us, that one should be declared on carbon.

21.4 *Source of further actuarial study*

21.4.1 The bibliography of this paper includes 59 sources on which it is partly based, including papers describing potential global energy constraints, the research into TEQs and the alternatives. This material is valuable in better appreciating possible long-term implications for economic growth and resource allocation. The proposal itself would probably take some years to introduce in terms of further feasibility studies, political agreement, development of administrative systems and implementation. Hence, at this stage, actuaries need to be thinking more about the implications of the issues it is intended to address rather than the detail of such a system.

22 Paper 16 – How Limited Oil Supply Can Lead to a Continuing Financial Crisis

Citation of paper: Tverberg, G., (forthcoming 2011). '*How limited oil supply can lead to a continuing financial crisis*', Energy, doi:10.1016/j/energy.2011.05.049

Location: http://www.sciencedirect.com/science/article/pii/S0360544211003744

22.1 *Abstract*

22.1.1 This paper aims to connect the decreasing availability of oil with its impact on the financial economy in oil importing nations, particularly the OECD, and in relation to our credit-based financial system.

22.1.2 Economic growth has been shown to be strongly correlated with the growth of the rate of oil extraction over the twenty year period 1986-2005.

22.1.3 Research has indicated that 11 of the 12 recessions in the United States since World War II have been preceded by oil price shocks. Tverberg asserts that "*the probability of oil price shocks preceding recessions in so many instances would appear to be extremely low, if a causal relationship were not involved.*"

22.1.4 Tverberg draws on the research of others to make the assertion that oil supplies are the exogenous variable and that economic output is driven by it (rather than vice versa).

22.1.5 Evidence is presented to show that global oil output has recently reached a plateau, and that the recent volatility in prices is a result of the inability of oil extractive industries to meet growing global demand. A consequence of this is that in the absence of supply side price stabilisers (namely increased oil supplies); market equilibrium must be reached by a reduction in demand caused by increased prices.

22.1.6 Tverberg then points out that most OECD economies are heavy users of oil products and significant oil importers. Consequently, OECD economies are substantially more sensitive to changes in the oil price.

22.1.7 When oil prices increase, and if oil consumption is not reduced, it will lead to additional out flows of funds from the national economy to oil exporting nations. This has the effect of reducing the amount of funds available for circulation within the economy, assuming no reinvestment of the funds from the foreign creditor. Additionally, due to the fundamental nature of energy inputs to industrial economies, increases in oil prices will lead to cost-push inflation pressures.

22.1.8 If these cost-push pressures translate into higher prices, higher rates of inflation are to be expected, leading to increases in interest rates. These increases in prices and interest rates will both act to reduce discretionary expenditure if salaries do not rise sufficiently to meet the higher costs of living and debt payment.

22.1.9 In the absence of a compensating expansion of consumer and corporate credit, which is unlikely when discretionary incomes are being squeezed, consumers will be forced to reduce discretionary expenditure. For example, buying new cars less frequently, eating out less often or taking fewer vacations. Some consumers may also default on loans as they divert limited available funds towards necessities.

22.1.10 The lack of effective demand in the economy caused by higher oil prices, may consequently lead to economic recession, higher unemployment, falling asset prices, particularly housing, and higher debt defaults.

22.1.11 These in turn act to reduce lending further and increase the cost of borrowing, creating a downwards spiral for the economy as it deleverages and until a new equilibrium is reached.

22.1.12 The implications on asset values, investment income and credit defaults may be severe.

22.1.13 The author concludes by drawing out three possible future scenarios:

- Firstly, that oil supplies are able to increase to meet world demand;
- Secondly, that they are able to increase, but still not meet world demand leading to OECD economies being outbid by emerging market economies which are less sensitive to higher oil prices; and
- Thirdly, that oil supplies continue to plateau or even fall, with OECD economies again outbid for oil. In both of the last two scenarios, the analysis points to declining living standards in OECD economies.

22.2 *Actuarial implications and importance*

22.2.1 Tverberg's paper paints a broad picture of the potential impact of higher energy prices on OECD economies. The mechanisms described are conceptually easy to grasp, but difficult to quantify.

22.2.2 Importantly however, the analysis shows that using historic financial data on default rates and investment returns may be highly misleading when assessing funding levels versus actuarial liabilities.

22.2.3 It suggests that there may be a need to review funding bases when providing advice either to our clients or to employers. This is particularly so for actuaries in advising on long-tailed business (i.e. pensions and life assurance), and for actuaries engaged in business management.

22.3 *Actuarial critique*

22.3.1 The paper relies on a broad-brush descriptive approach to reaching its conclusions. It does however contain a comprehensive list of references that would be useful in directing further study.

22.3.2 As a consequence of the descriptive approach, there is no numerical analysis or framework to provide a quantification of the likely effects of changes in oil prices. This means that it does not readily lend itself to making quantitative changes to assumed investment returns or credit default rates for the purposes of projection bases.

22.3.3 However, given the credible description of the causes and likely effects, it is important for actuaries to consider seriously the risks that such outcomes would pose for our clients and the wider public, however low-risk they may seem.

22.3.4 For those using stochastic techniques to present scenario analysis, it would be wise to ensure that any sets of simulations include examples of long-term or repeated economic contractions.

22.4 *Source of further actuarial study*

22.4.1 Actuaries could engage in analysis of the relative sensitivities of economies to oil price shocks at different levels of economic development.

22.4.2 Analysis of the correlation between credit default rates versus economic growth and changes in energy consumption would also be useful.

23 PAPER 17 – GLOBAL ENERGY CRUNCH: HOW DIFFERENT PARTS OF THE WORLD WOULD REACT TO A PEAK OIL SCENARIO

Citation of paper: Friedrichs, J. (2010) Global Energy Crunch: *How different parts of the world would react to a peak oil scenario*. Energy Policy Vol. 38 (8).

Location: http://www.sciencedirect.com/science/article/pii/S0301421510002843

23.1 *Abstract*

23.1.1 Although not pronouncing directly on the peak oil debate, the paper instead looks at the reaction of countries that have faced a short-term reduction in energy resources in the past as a guide to what may happen when the world passes the peak production rate of oil.

23.1.2 The paper cites three historical case studies: Japan in the period up to 1941, when it reacted with "predatory militarism" in order to safeguard supplies; North Korea, which opted for a "Totalitarian Entrenchment", preserving the resources of the elite and letting the rest of the population starve; and a slightly more positive example of Cuba, which when faced with the removal almost overnight of subsidies and resources from the Soviet Union managed to follow a path of "Socioeconomic Adaptation".

23.1.3 The author describes the military campaigns of Japan from 1918 as being solely driven by the obsession of securing natural resources in order to establish the country as a great power. The Japanese analysed this as the main reason for Germany's defeat in World War I and did not wish to follow suit. Resource-poor Japan, spurred on by an American trade embargo beginning in 1941, thus embarked on aggressive military campaigns in order to prevent fuel starvation and to achieve self-sufficiency in a Japan-centric regional economic bloc.

23.1.4 In the 1990s, North Korea reacted in an opposite fashion to Japan, retrenching in order to preserve elite privileges. One million people died from the resultant famine caused by the collapse of the nation's fossil-fuel-dependent agricultural system. The totalitarian government responded by implementing a system of allocated scarcity, thus managing to preserve itself and the elites that were its foundation.

23.1.5 Cuba, on the other hand, when faced with a 70% reduction in oil imports, reacted very much at a micro level. Neighbourhoods helped each other, small farms did better than state owned ones as they were less dependent on energy and machinery and traditional small-scale organic farming knowledge was reactivated – helped by a favourable climate.

23.1.6 Using these three 'model responses', the author predicts that larger countries with sizeable military forces will be likely to follow the Japanese example. Smaller more liberal countries may follow a socio-economic adaptation pathway, although much depends on how individualistic a society is. There will also be a shift in power from non-state to state energy companies and of course from oil importers to oil exporters.

23.1.7 The final part of the paper looks at the likelihood that alternative energy sources will simply replace falling oil production. The author is sceptical, since such changes take time and resources. He cites the end of slavery in the Southern United States where labour did not disappear but instead became much more expensive resulting in the region taking more or less 100 years to recover and adjust. He concludes that peak oil will cause neither a sudden collapse nor lead to a smooth transition but that the change will be painful.

23.1.8 The paper continues with a region by region prediction. Whilst Europe may cope better, being less individualistic than many other regions and more democratic, a bleaker picture is seen for the US and China. In Africa, the author predicts a greater role of communities whilst at the same time, increased conflict over scarce natural resources and challenges to undemocratic resource-rich countries. The conflict in South Sudan is cited as a relevant recent example.

23.1.9 The paper concludes with a review of current oil replacement options. The author suggests that natural gas and in particular shale gas are the most likely to take over backed up by coal over the next two decades. Even though written prior to the Fukushima disaster, the author concludes that nuclear power will only ever be marginal, while renewable energy will play an important role but still a minority one.

23.1.10 The paper ends with both a positive prescription – "*From an ecological viewpoint, the greatest hope for the mitigation of peak oil is a combination of conservation, energy efficiency, and renewable energy*" – and a more pessimistic projection of the likely result being an increase in greenhouse gas emissions as countries put in place desperate measures to extract any source of energy whatever the cost. Finally, the author concludes that, either way, "*infinite growth on a finite planet is impossible*."

23.2 *Actuarial implications and importance*

23.2.1 The paper is a useful reminder that there are significant unknowns regarding future energy provision and how countries and economies will adapt to scarcer and more expensive resources.

23.2.2 Although the paper does not specifically map out the implications, the general paths that economies may take – highlighted by the three examples cited – set out the context and background for future assumption setting.

23.2.3 No matter the response of countries, the general economic picture is likely to be lower investment returns, regional impacts on mortality and disability and inflation implications. The paper does not rule out that replacement energy sources could be found but doubts the abilities of economies to adapt in time to the transition required. At the same time, he urges serious attention to the "spectre of peak oil" and the global energy crunch as the most prudent action now.

23.3 *Actuarial critique*

23.3.1 The paper is not a technical study but a socio-economic overview of likely future paths. From an actuarial point of view, the implication of the paper is that our assumptions regarding future economic, investment, inflation and mortality development will need to be completely rethought given the likely impact of peak oil. Even in the most optimistic of scenarios, the transition will be difficult.

23.3.2 The conclusions will have particular implications for pension plans and life insurers. Financing of benefits will become increasingly difficult and future mortality developments difficult to predict.

E. INSTITUTIONAL INVESTMENT ISSUES

24 PAPER 18 – ADOPTION OF GREEN INVESTING BY INSTITUTIONAL INVESTORS

Citation of paper:	Amenc, N., Goltz, F., Tang, L. (2010). *Adoption of Green Investing by Institutional Investors: A European Survey*. EDHEC-Risk Institute.
Location:	http://docs.edhec-risk.com/mrk/000000/Press/EDHEC_Publication_Adoption_of_green_investing.pdf

24.1 *Abstract*

24.1.1 This paper reports on a survey of European investment management professionals' perceptions of "green investing". The paper also reviews some relevant literature about: definitions of green investment; motivations for, and obstacles to, green investment; and financial performance of green investments.

24.1.2 The authors use a broad definition of Socially Responsible Investment (SRI) as "*investments that combine investors' financial objectives and their concerns about environmental, social and governance issues*". They suggest this is closely related to sustainable development. The paper itself focuses on the narrower topic of green investing, i.e. investment that takes account of environmental considerations.

24.1.3 The paper outlines three approaches to green investment:

- thematic, which focuses on specific sectors such as clean energy;
- screening, which includes or excludes companies according to environmental criteria; and
- engagement, which focuses on dialogue with companies on environmental issues, with the aim of improving practices.

The paper also provides an overview of green investment products. The equity market is the most developed, but bonds and alternatives such as real estate and infrastructure funds are also available.

24.1.4 The paper gives an overview of the difficulties of integrating non-financial information into the investment approach, for example the problems of data availability, interpretation and standardisation, and the challenges of weighting information on companies' environmental impact, especially given that such information is often hard to quantify.

24.1.5 The survey concluded that green investment is a significant and growing area, with climate change being the most popular "green theme". This was considered unsurprising since climate change has been high on both media and political agendas for some time, and has resulted in the emergence of specific funds and products (e.g. emission markets).

24.1.6 The survey identified diverging views among investment professionals about the risk and return characteristics of green investments, and the use of inconsistent definitions and terminology.

24.1.7 The main motivation for green investment of those surveyed was "*responsibility for the planet and society*". Other motivations included marketing reasons and the potential for higher returns, lower risk and low correlation with existing investments.

24.1.8 The main obstacle to green investment was immaturity of the market, including insufficient offerings, lack of information about offerings, and a lack of credible standards for defining and assessing green investments. Other obstacles included lack of knowledge and the potential for lower returns and higher risks.

24.2 *Actuarial implications and importance*

24.2.1 This paper will primarily be of interest to those working in the investment field. The focus on investor perceptions rather than investment performance means that much of the content is not actuarial in nature. However, the paper does point to areas where further work is needed and actuaries would be well-placed to assist with this – see the sources of further study below.

24.2.2 There are significant limitations with a survey of this type (see below) and this limits the paper's importance. Nonetheless, the background information section may be useful to those who are unfamiliar with green investing or who want a summary of the research into the historic performance of green investments.

24.3 *Actuarial critique*

24.3.1 The survey which forms the centrepiece of the report had 97 responses. The sampling methodology and response rate are not specified. However, it seems likely that the sample was biased towards those with an interest in green investing since it used an optional questionnaire circulated by email. This undermines some of the conclusions, for example that small organisations tend to be more concerned about green investing than medium-sized organisations.

24.3.2 There was a wide range of respondents, including asset owners, asset managers and advisers. The report, however, did not acknowledge the different roles and potentially differing perspectives of such respondents, particularly in relation to motivational factors, nor attempt to analyse the results by type of respondent although the sample size was not large enough for any such analysis to be statistically credible in any case. Similarly, there was no geographical analysis or recognition of the potential variation between countries.

24.3.3 A common theme of the paper is the inconsistent definitions and terminology in use. It was not clear whether/how the questionnaire design had taken this into account, to maximise the consistency and usefulness of responses received.

24.3.4 The paper emphasises the inconclusive nature of the empirical evidence on financial performance of green investments and identifies this as an important area for further research. It does not acknowledge that past investment performance is not necessarily a good guide to the future, especially given the rapidly evolving definitions and approaches to green investing (some of the research quoted is now several decades old), and the potential for environmental considerations to have a greater impact on economic/investment outcomes in future.

24.3.5 The paper implicitly treats green investment as a specialist area, with little consideration given to investor engagement and/or the integration of environmental factors into mainstream investment approaches, both of which are becoming increasingly common[30].

24.4 *Source of further actuarial study*

24.4.1 The paper identifies the need for further research into the return, risk and correlation characteristics of green investments. This is an obvious area for actuarial involvement.

24.4.2 The paper also notes the importance of establishing a generally accepted definition of green investing and the difficulties of integrating non-financial information into the investment process. For example, interpreting and weighting information on companies' environmental impact. Whilst these areas are not strictly actuarial in nature, actuaries could make a significant contribution given their analytic skills and rigorous approach.

24.4.3 If this further work is carried out, it will be important to consider whether "green investing" is a helpful categorisation or whether the work should (for example) consider SRI more broadly. Note that a particular challenge in analysing the information available from previous research is the differing SRI-type definitions used both by researchers and practitioners.

25 Paper 19 – Funding Climate Change: How Pension Fund Fiduciary Duty Masks Trustee Inertia & Short-termism

Citation of paper:	Woods, C. (forthcoming, 2011) *Funding climate change: how pension fund fiduciary duty masks trustee inertia and short-termism. Chapter 11* in, Hawley, J., Kamath, S. and A.T. Williams (eds.) Corporate Governance Failures: The Role of Institutional Investors in the Global Financial Crisis. University of Pennsylvania Press: Philadelphia.
Location:	(Draft version): http://economics.ouls.ox.ac.uk/14217/1/wpg09-13.pdf

25.1 *Abstract*

25.1.1 This paper considers the legal and behavioural barriers to pension funds investing to take account of the risks and opportunities presented by climate change.

25.1.2 The legal position for pension fund trustees is considered, both in the UK and the USA, in relation to the fiduciary duty applicable to investment and its implications. A similar conclusion is reached in both countries, that there is some uncertainty as to how an issue like climate change can be recognised in investment decisions, in the context that the financial implications are themselves subject to much uncertainty, or are not appreciated by the financial community, and, it is suggested, seem to be ignored by the typical pension fund.

25.1.3 This latter contention, that climate change does not seem to be a major issue for most pension funds, also reinforces a legal barrier in that the Courts would look to what the conventional pension fund is doing, in deciding what a prudent policy for trustees is. Hence without a change in the law itself, change can only come if major pension funds themselves act together to change the conventional wisdom.

[30] See for example Eurosif's 2010 European SRI Study

25.1.4 The author makes an interesting comparison with the UK Companies Act 2006, which requires directors to have regard to "*the impact of the company's operations on the community and the environment*" and "*the likely consequences of any decision in the long term*" when promoting the success of the company. She does not consider the impact such provisions may have had in the corporate context but argues that a wider brief should be considered for pension funds given their economic power and that it is not necessarily inconsistent with the interests of their beneficiaries.

25.1.5 The author argues that pension funds could contribute to greenhouse gas emissions reductions in two ways. Firstly, they could consider carbon footprint as a risk that is set to increase as regulators and markets react to the increasing economic, social and environmental impact of climate change. In response, pension funds should introduce carbon footprinting as an additional metric in investment and look to use their relationship as shareholders to leverage further change. Secondly, they could target investments towards firms benefitting from climate change mitigation and adaption, such as those in the renewable energy market.

25.1.6 It is noted that, although in defined contribution pension funds investment decisions are, at least in theory, partly in the hands of the members through their choice of funds in which to invest. However, in practice most members remain in default funds put forward by the trustees.

25.1.7 The author maintains that the pension fund industry is slow to change and subject to short-termism, mentioning the conclusions of the first Myners Report in 2001. The paper concludes that there is no inherent conflict between pension funds' fiduciary duty and consideration of climate change risks and opportunities.

25.2 *Actuarial implications and importance*

25.2.1 The issues dealt with in this paper are crucial in considering the potential role of pension funds in combating climate change and actuaries need to be aware of them in advising such clients.

25.3 *Actuarial critique*

25.3.1 The conclusions of this paper are supported by the results obtained from a survey of trustee attitudes included in the 2010 Literature Review (*Paper 19*: Pension Fund Trustees and Climate Change), at least as regards conventional wisdom.

25.3.2 There have been attempts to clarify the legal position in the past, in particular the October 2005 paper produced by Freshfields Bruckhaus Deringer for the United Nations Environment Programme Finance Initiative, "A legal framework for the integration of environmental, social and governance issues into institutional investment". Their conclusion as regards the UK seemed to be that the existing law was not a barrier to recognising these issues, but, like the author, they noted that the absence of any recent case law, and perhaps an element of uncertainty, meant that problems of perception remained.

25.3.3 The paper does not attempt to review the changes which are taking place in the pension fund industry, for example the activities of the UK Sustainable Investment & Finance Association, the Institutional Investors Group on Climate Change or the major investment consultants. It does appear that there is now some momentum building in terms of initiatives being taken by some major pension funds, and the services being offered to trustees to help them address these issues. On the other hand, in terms of influencing companies, the inertia of institutional investors and structural communication problems are perhaps demonstrated by their limited impact on senior executive remuneration policies.

25.3.4 The author notes that UK pension funds hold only 13% of UK equities excluding managed funds held within insurance companies. However, she suggests they could have a profound influence on companies. This would seem to be more likely if such activities are co-ordinated with other institutional investors such as insurance companies and other investment managers and, indeed, overseas based pension funds. These do, however, operate under different legal structures and constraints.

25.3.5 It is also relevant to note that the typical UK pension fund now invests a substantial amount in overseas markets, approaching the same proportion as in the UK market, although their influence in any particular overseas market may be limited.

25.3.6 As the author notes, it is only the largest pension funds which are likely to have the resources to fully address any legal issues, and take the initiative in terms of building in the risks and opportunities arising from climate change into their investment processes. Actuaries working with such institutions should themselves take the initiative to ensure that the long term interests of their clients are being properly considered. Such activities will help to raise the game for the industry, and society, as a whole.

F. RISK MANAGEMENT & UNCERTAINTY

26 PAPER 20 – FAT-TAILED UNCERTAINTY IN THE ECONOMICS OF CATASTROPHIC CLIMATE CHANGE

Citation of paper: Weitzman, M. L. (2011). *Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change*. REEP Symposium on Fat Tails.

Location: http://www.economics.harvard.edu/faculty/weitzman/files/REEP2011%2Bfat-tail.pdf

26.1 *Abstract*

26.1.1 This article is a follow up from Weitzman's 2009 paper 'On modelling and interpreting the economics of catastrophic climate change', *The Review of Economics and Statistics*, Vol XCI No.1.[31] Weitzman's earlier paper was reviewed in the 2010 edition of this Literature Review. Weitzman's follow up is meant as a less technical discussion for general economists. It revisits some basic issues concerning structural uncertainty and catastrophic climate change.

26.1.2 Weitzman uses empirical examples to argue that it is implausible that low-probability high-negative-impact events would not influence an economic analysis of climate change. He integrates these examples with theory to argue that the danger of extreme climate change should drive the policy response.

26.1.3 The empirical examples offered are five "exhibits", which are used to demonstrate the uncertainty in climate change and that the possibility of ruinous climate change needs to be taken seriously.

26.1.4 Weitzman argues that the uncertainties highlighted by his intuitive argument, using his exhibits, must influence the outcome of any reasonable Benefit-Cost Analysis (BCA) of climate change. By BCA he means some overall economic analysis centred on maximizing welfare by

[31] See http://www.economics.harvard.edu/faculty/weitzman/files/REStatFINAL.pdf

comparing the benefits and costs of more action to reduce climate change versus less. Weitzman further states that his definition of BCA in the context of this paper is so broad that it overlaps with Integrated Assessment Models (IAM), as used for example by the IPCC. He treats the two as essentially interchangeable.

26.1.5 For simplicity Weitzman begins by setting up a "standard BCA of climate change". He states that there is no such thing as a standard BCA, but it is an allowable simplification that enables the examination of the general characteristics of BCAs.

26.1.6 Five exhibits are provided to demonstrate the uncertainty in climate change:

26.1.7 **Exhibit 1: Past and Present Greenhouse Gas Concentrations.** The pre-industrial-revolution level of atmospheric CO_2 was 280 parts per million (ppm). Highly reliable data from ice-cores shows that CO_2 varied during the last 800,000 years roughly between 180 and 280 ppm and has never been above 300 ppm in that time period. Currently, CO_2 concentrations are over 390 ppm, and climbing. Weitzman finds it remarkable that the standard BCA of climate change takes little account of the magnitude of uncertainties in extrapolating climate change so far beyond past experience.

26.1.8 **Exhibit 2: The Uncertainty of the Climate-Change Response.** Weitzman states that there is a high degree of uncertainty about the response of the climate to the unprecedented forcing described in Exhibit 1. He uses the uncertainty in the parameter of Equilibrium Climate Sensitivity, S, as a means to examine this uncertainty. The IPCC in their 4th Assessment report define equilibrium climate sensitivity as "a measure of the climate system response to sustained radiative forcing. It is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations. It is likely to be in the range 2 to 4.5°C with a best estimate of 3°C, and is very unlikely to be less than 1.5°C."

26.1.9 The IPCC defines likely as a probability above 66% but below 90%, which would mean that the probability that climate sensitivity is greater than 4.5°C is between 5% and 17%. A more recent survey of leading climate scientists from 2010 indicates that the high end of this range is more likely to be appropriate, so Weitzman uses 15% for his analysis. Weitzman then demonstrates how the behaviour of the far tail of the distribution of S depends upon whether the probability distribution is thin or fat-tailed. To examine this effect, he calibrates parameters for Normal (thin tailed) and Pareto (fat tailed) distributions for S by assuming that the probability that S > 3°C is 0.5 and the probability that S > 4.5°C. These distributions show very different behaviour. The thin-tailed distribution produces a probability that S > 10°C of less than 0.0001%. On the other hand, the fat-tailed distribution has a probability that S > 10°C is 1.4%. In other words, if this fat-tailed distribution for S is appropriate, then the probability that doubling CO_2 from 280 to 560ppm would ultimately produce >10°C temperature rise is more than 1 in 100.

26.1.10 **Exhibit 3: A Physical Basis for Catastrophic Outcomes.** Exhibit 3 concerns possibly disastrous long run bad-feedback components of the carbon cycle that are currently omitted from most general circulation models. The chief concern here is that there may be components of the climate system that should be added on to the fast feedback sensitivity outlined in Exhibit 2, to get a true picture of long-term warming. These components would be part of the holistic climate system including slow feedbacks. The corresponding measure of this system is called "earth system sensitivity". Examples of known slow feedbacks include the huge volume of trapped GHGs in tundra permafrost and boggy soils (mostly as methane, a particularly potent GHG), and the more remote possibility of heat-induced releases of the even-vaster offshore deposits of methane trapped in the form of clathrates.

26.1.11 **Exhibit 4: Damages of Extreme Climate Change.** In Exhibit 4 Weitzman deals with what he calls a “cavalier treatment of damages” in the standard BCA. For example, the standard treatment uses a mathematical form that estimates, for example, that if global average temperature increased by 10°C then human welfare would reduce by just 19%. Weitzman finds such low damages at high temperature rises unconvincing.

26.1.12 To look at extreme climate change Weitzman uses a global average temperature rise of 10°C as a reference point recognizing that the full temperature rise may take centuries to attain. This is because of a recent study that estimated that a global average temperature increase of 11-12°C would render regions where currently more than half of today’s human population live as effectively uninhabitable. The reason is that in these regions the wet-bulb temperature would exceed 35°C at least once a year. Wet-bulb temperatures combine heat and humidity into a single figure. 35°C would cause death from heat stress after about six hours of exposure. This understates the effect, because physical work outdoors would be impossible even at some wet-bulb temperatures lower than 35°C. By contrast, today the highest wet bulb temperature anywhere on Earth is about 30°C.

26.1.13 **Exhibit 5: Discounting the Distant Future.** Weitzman addresses the effect of compounding a constant positive interest rate. By carrying out such discounting, even earth-shaking events like disastrous climate change do not much matter when they occur in the deep future. When exponential discounting is extended over very long time periods the outcome of a BCA analysis is highly dependent on the choice of a discount rate.

26.1.14 Furthermore, Weitzman does not see a deep reason or principle to allow the extrapolation of past rates of return on capital into the distant future. The apparent lack of trend in past rates of return is purely based upon empirical observation of just the last two centuries since the industrial revolution began in Britain. It is not based on any underlying theory that would allow confident projection of past numbers far into the future.

26.1.15 Additionally, there is a normative/ethical dimension to choosing a discount rate to evaluate costs across generations which is difficult to incorporate in a standard BCA.

26.1.16 Weitzman sums up by looking at his exhibits together. He concludes that the conventional economic analysis of climate change consists of a very long chain of tenuous inferences fraught with big uncertainties in every link. An example of a chain of uncertainties begins with the unknown base-case GHG emissions, the amount of GHGs that will be emitted in the business as usual case, without action to reduce emissions; compounded by uncertainties about how available policies and policy levers will affect actual GHG emissions; compounded by uncertainties about how GHG flow emissions accumulate via the carbon cycle into GHG stock concentrations etc. These compounded uncertainties result in a lengthy cascade of uncertain events and thus, Weitzman argues, a fat-tail on the potential negative outcomes of climate change.

26.1.17 Weitzman cautions economists against pursuing an artificially precise analysis by ignoring the low-probability high-impact catastrophic scenarios. This is true even if policymakers want definite answers rather than ranges. Marginalizing the possibility of extreme climate change would be a serious mistake, because it is that possibility that makes climate change such a grave threat in the first place.

26.1.18 Weitzman recognises that others produce analyses that have much less severe outcomes. However, he uses an analogy of fire insurance for a householder to strengthen the case of his analysis. If two analysts, both credible, provide advice and one says that complete fire insurance is needed, and the other says it is unnecessary, the prudent householder would be advised to listen to the former. Weitzman recognises that climate change is not the only catastrophic threat to humanity, and other threats deserve their own analysis. He refers to his previous paper where he lists several examples e.g. asteroid strike, but gives reasons why climate change is particularly troubling.

26.2 *Actuarial implications and importance*

26.2.1 The main thrust of the argument of this paper is that economic advisors and policy setters should be aware of the high-level of uncertainty of the potential negative outcomes from climate change when recommending and setting policies. Models currently in use do not recognise the potential fat-tail of negative outcomes, and so decisions are being made by leading policy setters based on incomplete (and perhaps even inaccurate) estimates.

26.2.2 Actuaries, with experience in modelling, understanding and conveying uncertainty, can play a key role in framing and explaining the uncertainty of negative outcomes of climate change. Actuaries are experts in this area with in-depth experience of analysing uncertain variables with a view to convey the level of uncertainty to senior management / board members. Actuaries use methods such as giving examples of confidence intervals, ruin probabilities and return periods in order to help convey the uncertainty of a variable to non-technical individuals.

26.2.3 Actuaries can play a key role in climate change analysis by helping economists and other professionals explain these uncertain variables to policy setters.

26.3 *Actuarial critique*

26.3.1 The argument put forth in the paper, as the author himself acknowledges, is a “soft-science” intuitive argument with only a few key pieces of evidence to back up claims made (for example, the existence of large methane deposits trapped in permafrost, and ice core data which shows the sudden large rise in CO_2 concentration compared with the pre-industrial level). However, his argument is no less strong for this because it is the very absence of certainty in climate science and economics that Weitzman is pointing out. Weitzman persuasively argues that uncertainty in the bad-case tail of climate change is insufficiently considered in conventional policy analysis.

26.3.2 Weitzman is essentially saying that climate change should be treated as a problem like catastrophe insurance, where the low-probability, high-severity outcome drives the response.

26.3.3 Actuaries commonly have to carry out risk analyses and forecasts with incomplete and imperfect information. For example, in assessing solvency and capital adequacy for financial companies, actuaries often have to evaluate and attempt to measure threats which might render a company insolvent, where those threats have a probability of only 1 in 200 over a one year period. Hence often, the actuary has to estimate probabilities and damages from very little data and use imagination to assess the outcome of events that have no exact historical parallel. An example of such an event would be the destruction of the Twin Towers in New York on 9th September 2001, which was the biggest insurance loss of all time. In the case of climate change it seems entirely appropriate that a scenario based intuitive and common-sense style of argument should be used. False precision should be guarded against. Models can help to understand a problem, but actuaries know well that the outputs are only as good as the modal formulations and inputs that go into them.

26.3.4 The uncertainty in climate sensitivity can be illustrated by the following diagram, which plots several estimates for the PDF for climate sensitivity together.

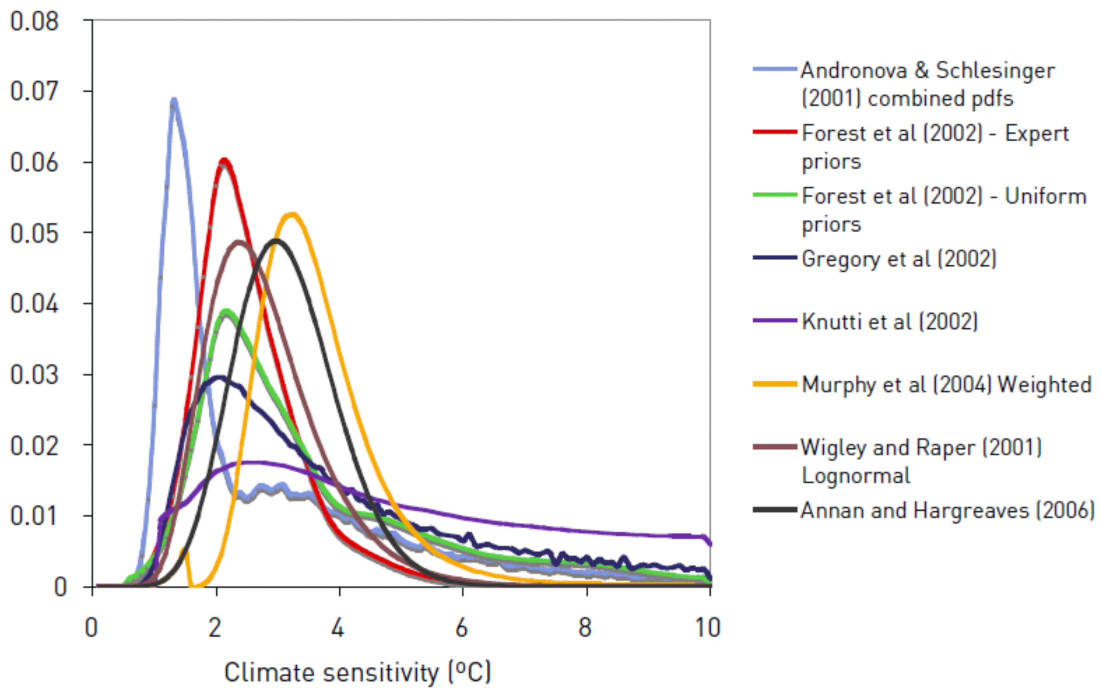

Fig 7: Dr. Baer, P. (2006) 'Nine published PDFs (probability density functions) for the climate sensitivity', IPPR, London, UK[32]

26.4 *Source of further actuarial study*

26.4.1 There are several areas where the actuarial skill set could be usefully employed.

26.4.2 Firstly, actuaries can begin to apply a risk management approach to climate change where tail risk is the focus. Approaches used in catastrophe insurance pricing and especially capital modelling might be a starting point for an "actuarial view" of climate change.

26.4.3 Secondly, actuaries might be able to contribute towards understanding of model uncertainty and limitations in modelling. This is a particular need when some are sceptical of climate science in general. There is a simple point that greater model uncertainty should be seen to increase the perceived risk and the need to act, rather than alleviating concern.

26.4.4 Thirdly, discounting is an area of particular expertise for the actuarial profession and considerations of discount rates in climate modelling might be a focus for future study.

[32] See Baer, P., Mastrandrea, M. (2006) *High Stakes: Designing emissions pathways to reduce the risk of dangerous climate change*, Institute for Public Policy Research (IPPR), London, UK. Available at http://www.ippr.org/images/media/files/publication/2011/05/high_stakes_1540.pdf Accessed Sep 2011

27 Paper 21 – Degrees of Risk: Defining a Risk Management Framework for Climate Security

Citation of paper: Mabey, N., Gulledge, J., Finel, B., Silverthorne, K. (2011). *Degrees of Risk: Defining a Risk Management Framework for Climate Security*. Third Generation Environmentalism (E3G).

Location: http://www.e3g.org/images/uploads/Degrees%20of%20Risk_Defining%20a%20Risk%20Management%20Framework%20for%20Climate%20Security_Full%20Report.pdf

27.1 *Abstract*

27.1.1 This paper explores the lessons learnt in managing national and international security risks. These lessons are applied to develop a robust risk management approach for effectively managing the full range of climate security risks. The paper draws from a series of closed-door meetings held by E3G with US and European security, intelligence and defence officials over two years. The report finds that current responses to climate change are failing to adequately manage the full range of climate security risks and that there is a mismatch between the analysis of the severity of climate security threats and the political, diplomatic, policy and financial effort countries expend to avoid them, leading to the crux question, what would an appropriate risk management strategy to deliver climate security look like?

27.1.2 The paper revisits some of the first principles of risk management as used by the security community. Risk management should consider both known and unknown variables, analyse possible threats and vulnerabilities, and implement suitable strategies to manage the risk. These principles are used to make decisions on matters of national security, including situations, where decisions have to be made using incomplete information and where future events are uncertain. Risks to national security can rarely be quantified in absolute terms; hence the security community has to compare short-term risks to long-term risks. They have to make decisions using inadequate data and models, which predict very different outcomes. This approach has been used to manage various global security threats, from the Cold War, to nuclear proliferation, to terrorism.

27.1.3 The lack of adequate action to deal with climate change has often been justified on the grounds of the ‘uncertainty’ associated with climate change. However, this rationale is unjustifiable for conventional security risks. For example, it would be hard to imagine governments arguing that counter-terrorism measures are unnecessary due to because the threat of attack was uncertain. Yet, precisely this argument is used by opponents of action on climate change to argue against even small measures taken to mitigate or build resilience to the threat.

27.1.4 The paper highlights the fact that national security issues are often the focus of intense and prolonged public and political debate concerning appropriate responses and risk management strategies, sometimes taking a decade or more to resolve. However, in the case of climate change, the authors stress that we do not have the luxury of such time. Rather, every day that action is postponed, the associated risks become incrementally and irreversibly higher. There is an urgent need to decide on our response to climate change through a risk management framework – i.e. through frank debate concerning the level of risk we are prepared to take and the consequences of action and inaction. There is a strong implication in the paper that a rational risk management approach should be used in dealing with the risks of climate change, rather than applying unhelpful partisan perspectives of being climate “believers” or “sceptics”.

27.1.5 The report proposes that each country should develop a risk management strategy based on the following 3-Tier Framework:

- Aim to stay below 2°C (3.6°F) of warming.
- Build and budget assuming 3-4°C (5.4-7.2°F) of warming.
- Contingency plan for 5-7°C (9-12.6°F) of warming.

27.1.6 Although the report suggests each country should develop its own approach based on detailed analysis of its own vulnerabilities and interests, the report makes ten specific recommendations for common actions governments around the world should collectively prioritise for each emissions trajectory in order to implement this framework effectively. These recommendations include:

- The need to carry out independent national climate security risk assessments to collect vital information for formulating an agreement on global action.
- The need to develop more sophisticated approaches to climate change adaptation policies which address "perfect storm" events and assess their impacts on social stability.
- The need to prepare robust contingency plans to govern the implementation of "crash programmes" of rapid mitigation and/or geo-engineering.

27.2 *Actuarial implications and importance*

27.2.1 The risk management principles described in the paper are something actuaries will immediately recognise and can help in further formulating and developing, especially where applicable to financial risks. The approach taken by the security community for risk management could be compared to the risk management techniques used by actuaries (e.g. for Solvency II work) and both the actuarial and security community could improve the methodology they use.

27.3 The effects of climate change will surely affect the insurance industry in various ways and to that extent actuaries have a professional responsibility to be aware of the risks of climate change and pro-actively participate in strategies to manage the unavoidable risks and avoid the unmanageable risks.

27.4 *Actuarial critique*

27.4.1 This paper's aim is to put risk central to the debate about climate change. This is a very worthwhile aim, and it is a valuable contribution to the debate on climate change. In our critique we refer also to Weitzman's paper (*Paper 20*), reviewed in this report.

27.4.2 The three tier framework as outlined above is a useful concept, insofar as it focuses attention on the risk of high temperature increases. However, in the context of Weitzman, we find the levels of warming chosen in the report to be problematic. The report suggests that building and budgeting should be carried out assuming 3 to 4°C of warming and contingency plans should be made for 5 to 7°C. The problem is that there are many unknowns about how the climate system would change and crucially, how the human system would react to any given level of warming. We cannot know whether it is possible to make our complex global civilization resilient to higher levels of warming. If the human system breaks down, partially or completely, then plans will not be implemented. It would be analogous to the Roman Emperors making plans for after the fall of the Roman Empire.

27.4.3 Even less than 2°C warming carries a risk of "large scale discontinuities". As the report points out, as the scientific understanding of the climate system improves, the estimation of the level of risk increases. This is graphically illustrated in the diagram below (sometimes known as the "burning embers" diagram) from the report, which shows the increasing level of concern caused by improvements in climate science after the IPCC's third assessment report. Climate science continues to develop and we wonder if this trend has further to run.

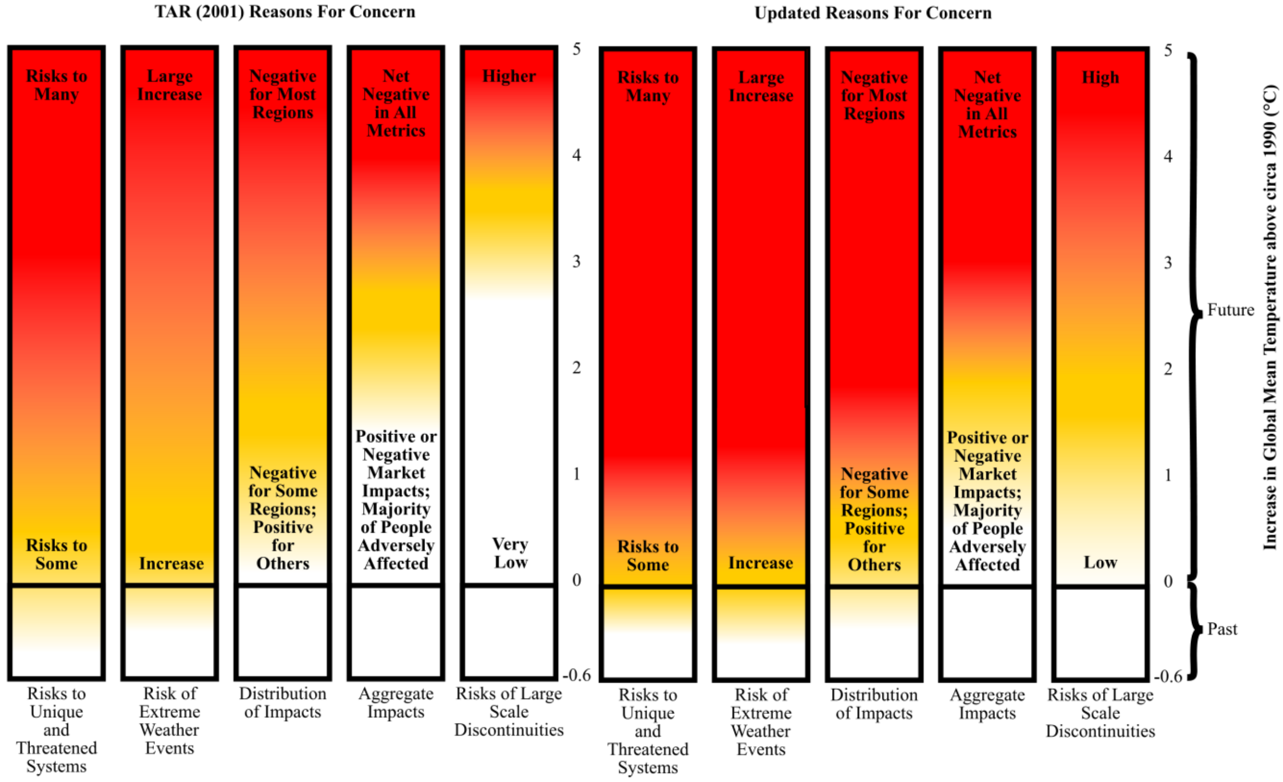

Fig 8: Based on *Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Figure SPM-2. Cambridge University Press.

27.4.4 Geoengineering is briefly mentioned in the report, along with ways to sequester carbon from the atmosphere such as artificial trees, biochar and biomass plus carbon capture and storage. We would suggest that a risk management framework should put much greater emphasis on measures such as these that reduce warming and therefore reduce the degree of uncertainty in outcomes, for which it is extremely hard to plan.

27.5 *Source of further actuarial study*

27.5.1 Actuaries can help in the statistical modelling of climate risks by peer-reviewing the models and data used to model the sources of climate risk, such as rising temperatures, increasing levels of carbon dioxide etc. Actuaries have a more direct role to play in modelling the financial and economic effects of climate change. For example, how should long-term inflation be modelled in economic scenario generators given the risk of climate change? How will interest rate expectations and credit swaps be affected by climate change? These are very complex questions, which actuaries should seriously consider using their technical skills and experience of modelling new risks.

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28.1.2 Special thanks to Gordon Morrison for his continued support and contributions in the establishment of this and previous literature reviews.

28.1.3 The editors would also like to thank all of the people, who are too numerous to name individually, who have given freely of their time to contribute to and support the project.

28.1.4 Additional thanks is extended to Ruth Loseby, Research Manager for the Actuarial Profession for her sound advice and willing assistance which has made the process of producing this review substantially easier than it would otherwise have been.

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30 Appendix 2 – Glossary of Terms

2P reporting	Declaration of oil reserves based on proven + probable accumulations. This includes both known reserves and those with a 50% confidence level of recovery.
Albedo feedback	Albedo refers to the reflecting power of a surface. Albedo feedback is a positive feedback climate process where a change in the reflective surface area (e.g. ice, snow, glaciers), alters the power of its reflective ability.
Albedo flip	The process by which sunlight previously reflected by white ice is suddenly absorbed as ice melts to become the dark surface of open water.
Anthropocene	A recent, informal geological term used to mark the era during which the extent of human activities have had significant impact on Earth's ecosystems. The Anthropocene has no precise start date – some argue it began with the Industrial Revolution in the eighteenth century, others with the rise of agricultural practice many thousands of years ago.
Cenozoic era	The geological era spanning the period 65.5 million years ago to the present. It is defined as beginning with the extinction of the last non-avian dinosaurs at the end of Cretaceous period and continues today.
Clathrates	A chemical substance which consists of a lattice of one type of molecule trapping and containing a second type. Of particular concern are methane clathrates, solid compounds which contain large amounts of methane trapped in a crystal structure of water, forming a solid, like ice. Large deposits of methane clathrates have been found under sediments on the Earth's ocean floors. The worldwide amounts of methane bound in this manner is conservatively estimated to total twice the amount of carbon to be found in all known fossil fuels on Earth.
Eemian period	An interglacial period which began around 130,000 years ago and ended about 114,000 years ago. It was the second-to-latest interglacial period of the current Ice Age, followed by the current Holocene period.
Energy Return on Energy Invested (EROEI)	The ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource.

Export Land Model	Based on the work of geologist Jeffrey Brown, the Export Land Model models the decline in oil exports that are a result of an oil-exporting nation experiencing both a peak in oil production and an increase in domestic oil consumption. In this instance, exports decline at a far faster rate than the decline in oil production alone.
Fat-tailed distribution (also referred to as a 'long-tailed distribution')	The term refers to a probability distribution that exhibits large 'skewness' or 'kurtosis'. Typically this is characterised by higher probabilities of extreme events (i.e. fatter tails). As the term is usually comparative in nature, an implicit comparison is often being made with a normally distributed variable with the same mean and standard deviation.
GHG	Green House Gasses including carbon dioxide, methane, water vapour, nitrous oxide and ozone
Holocene period	A geological epoch which began around 10,000 years ago and continues until the present. It is identified with the interglacial warm period experienced today, and encompasses the history of the growth of human impact worldwide.
Interglacial period	A geological interval of warmer global average temperature lasting thousands of years that separates consecutive glacial periods within an ice age. The current Holocene interglacial has persisted since the end of the Pleistocene, about 11,400 years ago.
IPCC	Intergovernmental Panel on Climate Change
IRP	International Resource Panel
Milankovitch oscillations	Changes in the Earth's climate based on the collective effects of changes in the Earth's movements. This term is named after the Serbian civil engineer and mathematician, Milutin Milanković, who studied and theorised that variations in the Earth's orbit of the amount by which it deviates from a perfect circle, its axial tilt and changes in orientation of its rotating axis impact on its climatic patterns through orbital forcing.
Orbital forcing	The effect on climate of slow changes in the Earth's axis and shape of its orbit.
Paleoclimatology	The study of the changes in climate taken on the scale of the entire history of Earth.

Pleistocene	The epoch between 2,588,000 to 11,700 years ago, before the Holocene, spanning the Earth's most recent period of repeated glaciations.
Tropopause	The atmospheric boundary between the troposphere and the stratosphere. Moving upwards, it is the point at which air ceases to cool with height and become almost completely dry.
Tundra permafrost	Tundras are biomes where tree growth is stunted by low temperatures and short growing seasons and where the subsoil is usually permafrost – that is to say the soil is permanently frozen. Permafrost tundra includes large areas of northern Russia and Canada. The concern in relation to climate change is that permafrost is a vast sink for carbon in the form of peat and methane. The volume of this carbon is so vast as to be twice as much as that which currently exists in the atmosphere. As global warming causes the permafrost to thaw, this could prove a devastating negative feedback mechanism, releasing huge quantities of carbon into the atmosphere leading to runaway climate change.
Wet-bulb temperature	A type of thermometer measurement that is used to indicate atmospheric humidity by wrapping a standard mercury-in-glass thermometer in wet muslin and measuring the temperature after water evaporation has had a cooling effect on the thermometer. This temperature reading will be lower than that of a dry-bulb thermometer. The rate of evaporation from the wet-bulb thermometer depends on the air humidity; evaporation is slower in more humid air and vice versa. For this reason, the difference in the temperatures indicated by the two thermometers gives a measure of atmospheric humidity.