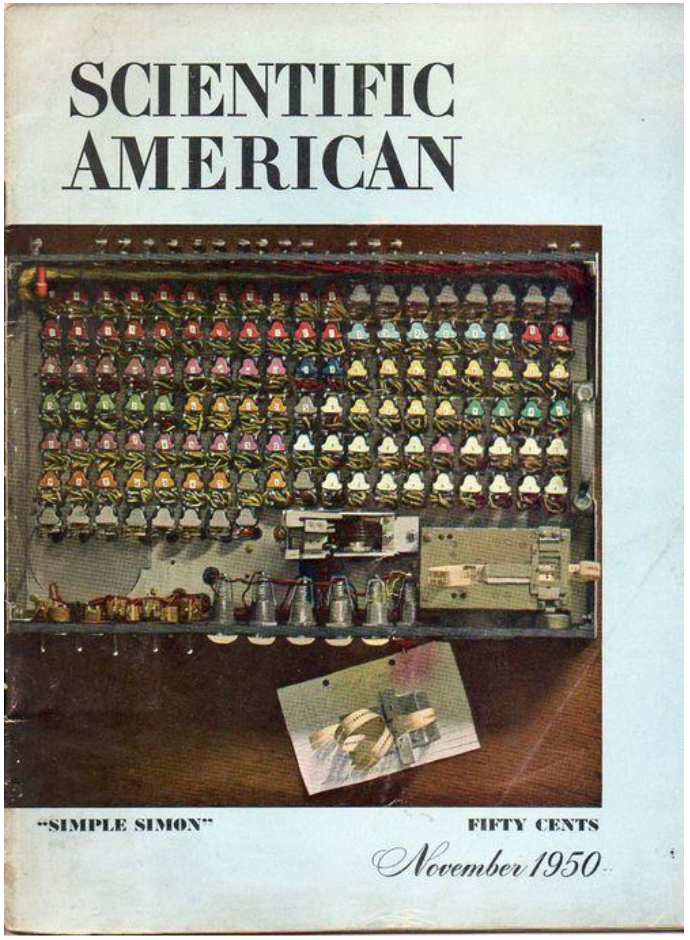
Science Advice to Government: Legacies of the 20th Century and the Challenges for the 21st

Professor Sir John Beddington
Oxford Martin School, Oxford University

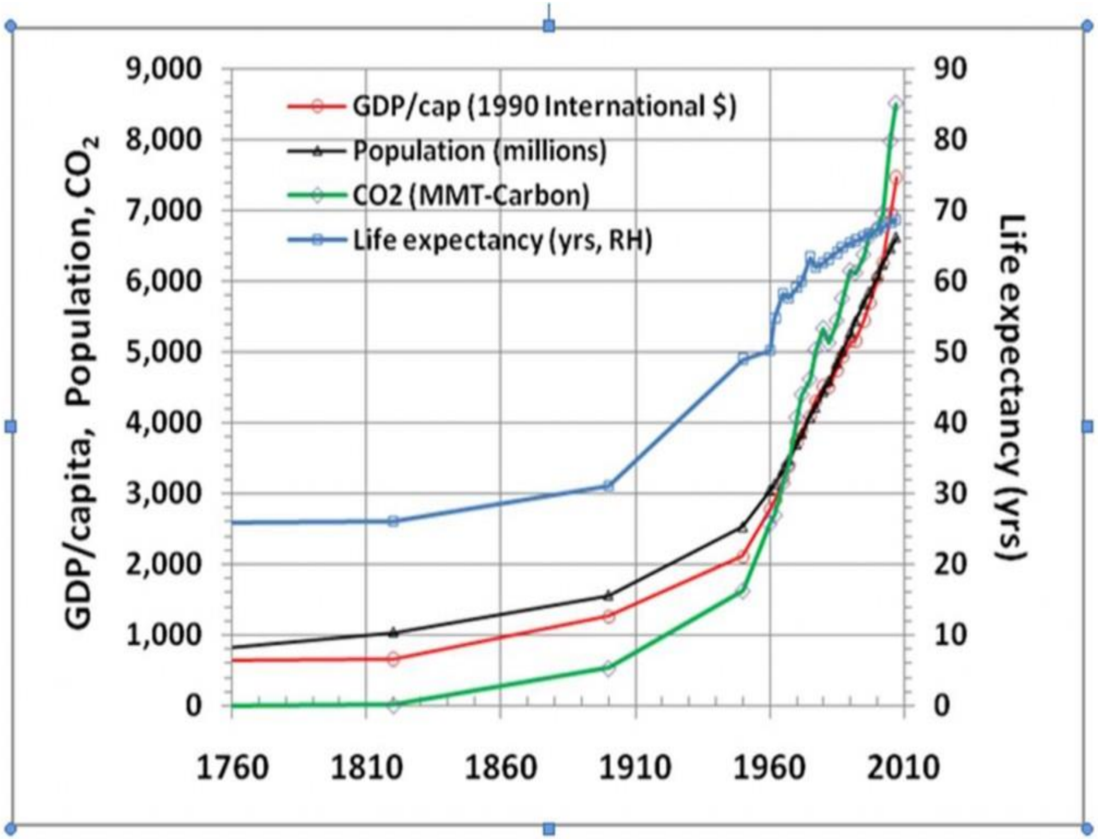
26th January 2016
York Philosophical Society

The state of the world in 1950

- No knowledge of DNA
- No widespread use of antibiotics
- Few co-ordinated vaccination programs
- Serious threats from smallpox, polio, whooping cough, diphtheria, and syphilis
- Little international co-ordination for scientific research
- Only the most primitive of computers
- Cost of oil (inflation-adjusted): $26/barrel
- No space travel, no satellites
- No contraceptive pill



The last half of the 20th Century: five decades of exponential growth and achievement



Innovation & scientific progress

Disease & poverty alleviation

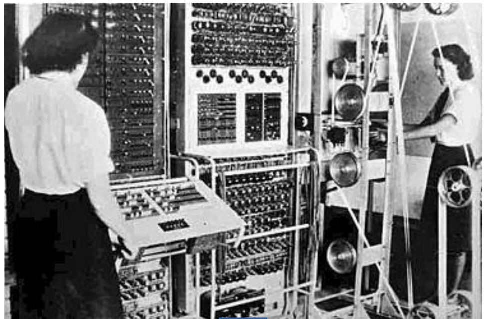
Massive population growth

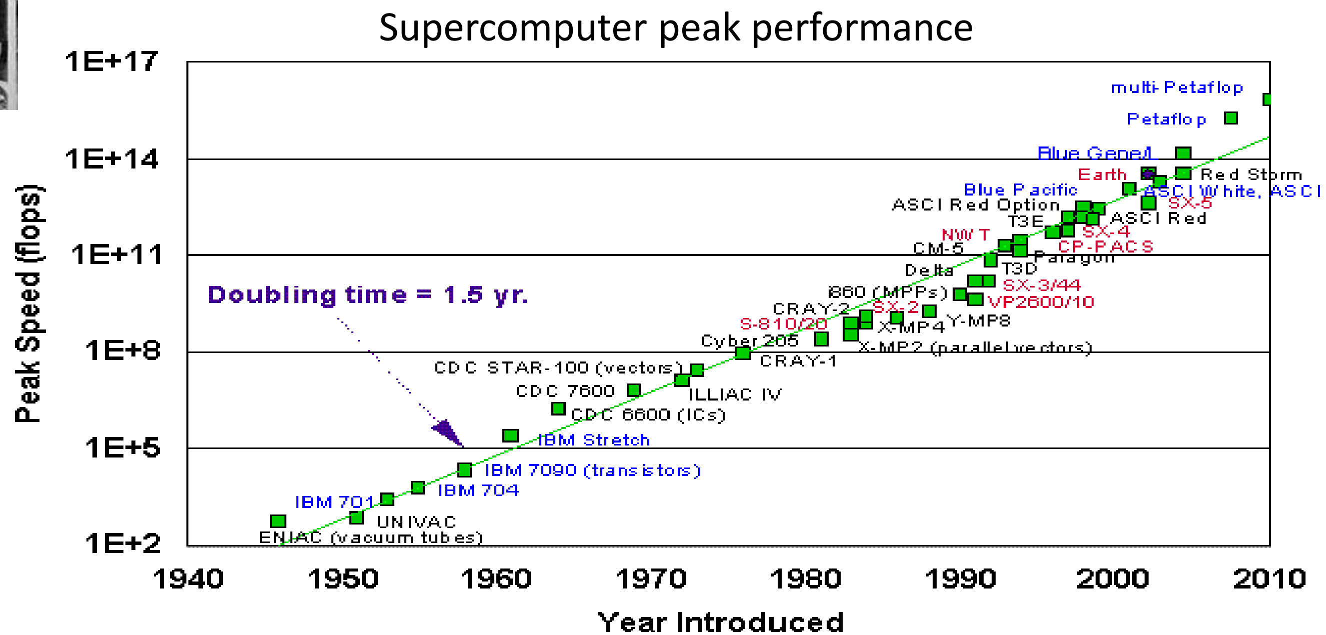
Large-scale natural resource exploitation

Substantial ecosystem service degradation

Acceleration of greenhouse gas emissions

Technological Progress





1944: ‘Colossus’, the first electronic digital programmable computer

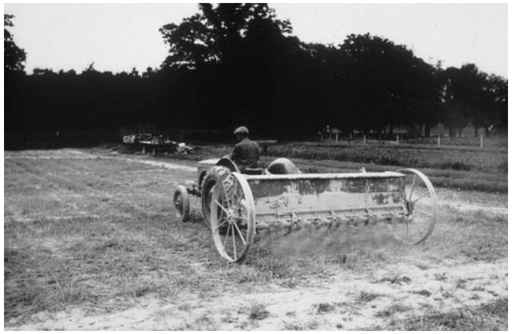
1950s: vacuum tubes evolve into integrated circuits

1970s: Intel introduces microprocessors

1980s: first mass-produced microprocessor-based portable computers

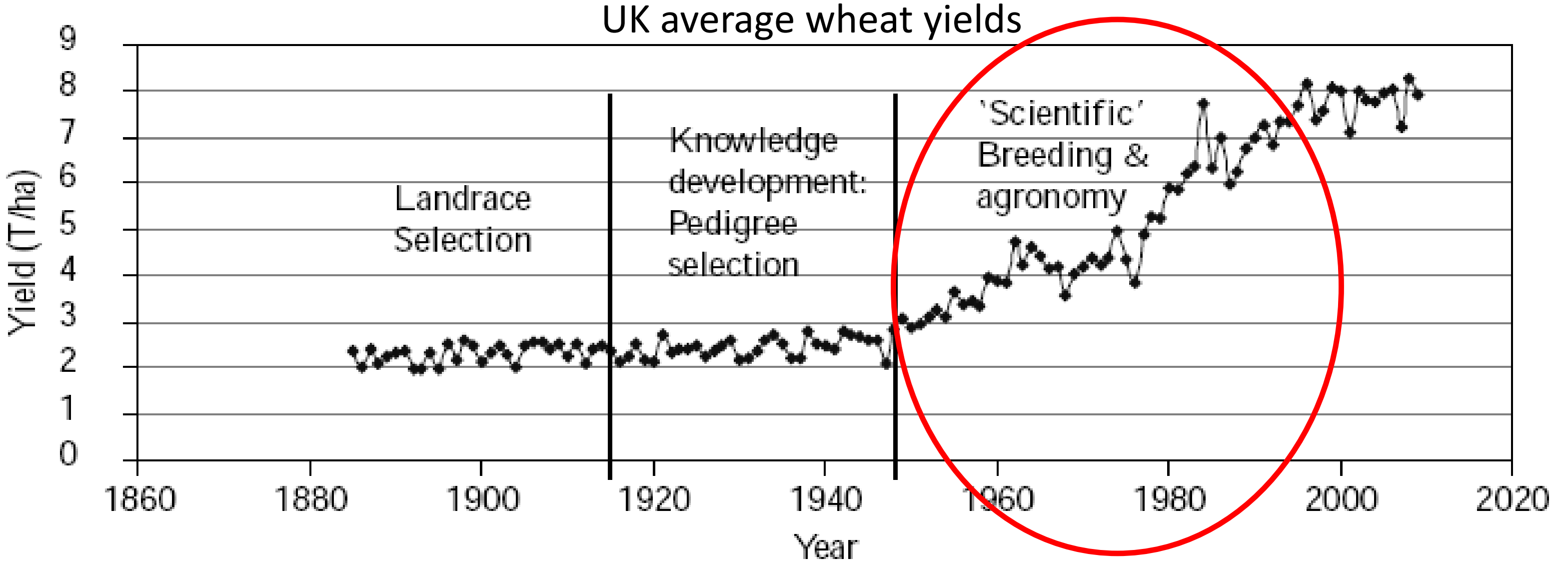
1990s: the era of mobile computing begins

Agronomy Progress



(l) 1954 and (r) 2003: Rothamsted's Classical Experiments on wheat, grassland, barley & fallow land have been running since 1854

The Green Revolution: modern irrigation techniques, pesticides, synthetic nitrogen fertilisers



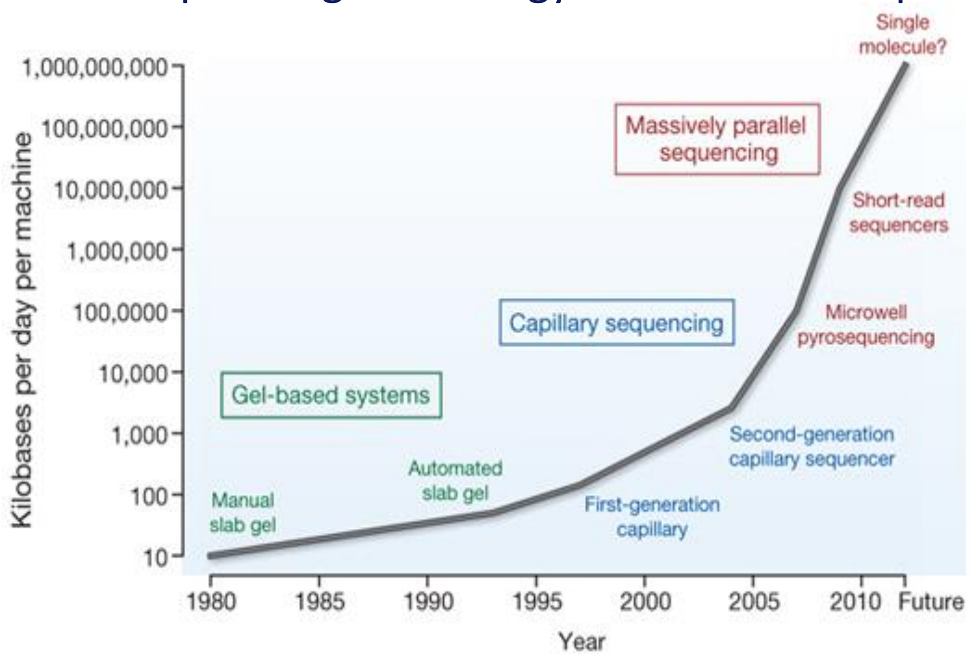
Global food production is 3x what it was in 1950

The world produces 30% more calories per person than in 1960

Biological progress

1953: DNA double helix structure mapped by Watson & Crick
1972: first recombinant DNA created
1980: first genome sequenced
1995-2014: >180 genomes sequenced

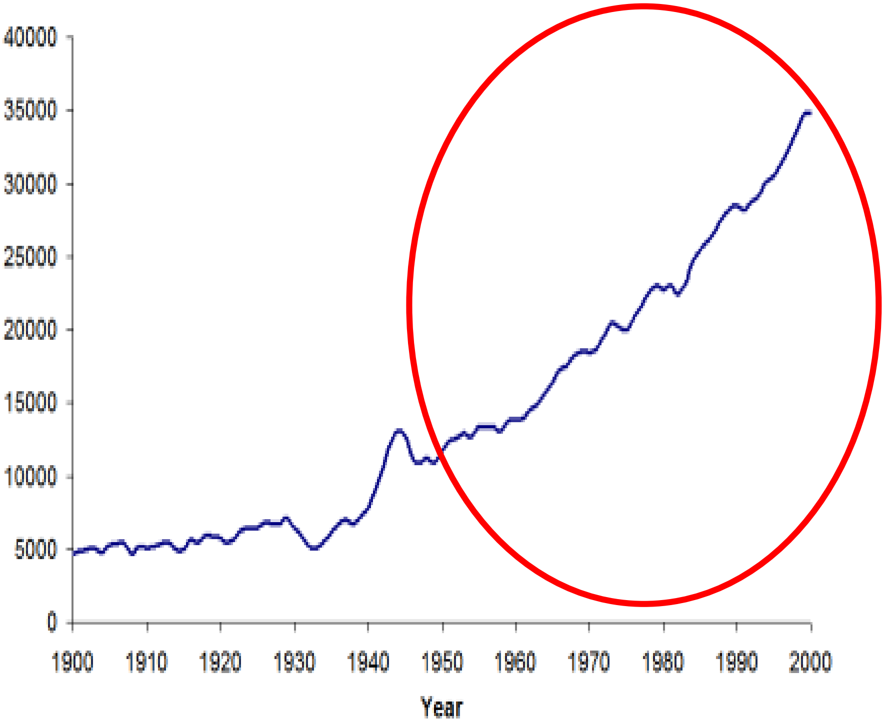
DNA Sequencing technology: faster and cheaper



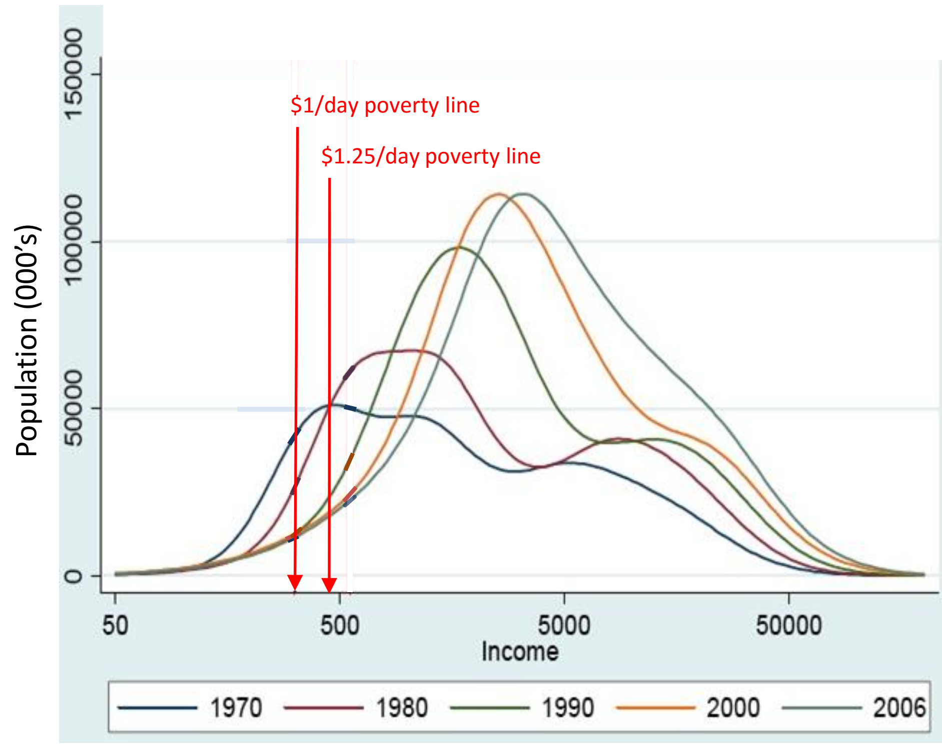
Michael R. Stratton *et al*, ***Nature* 458**, 719-724(2009)

Human wellbeing indicators: wealth

Real GDP per Capita (2000 dollars)



World Distribution of Annual Income (USD)



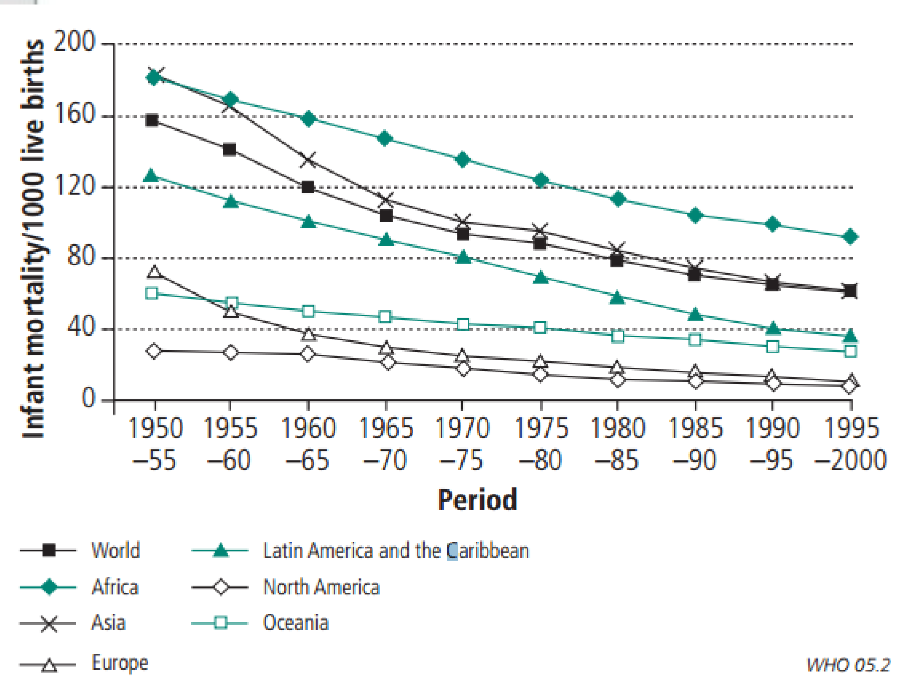
Source: Pinkovskiy and Sala-i-Martin, 2009

Human wellbeing indicators: health

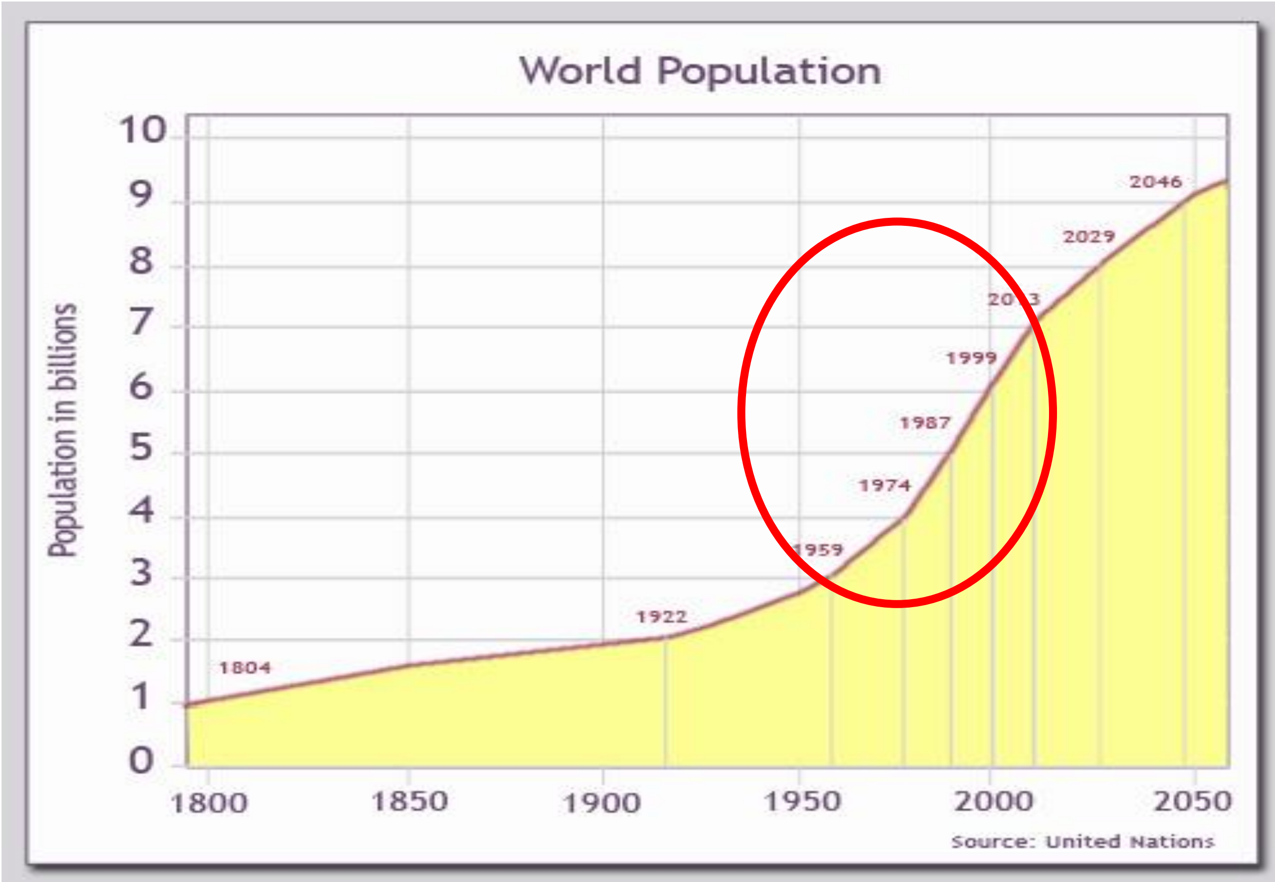
Evolution of life expectancy at birth in the world by level of development Unity: years							
	1950-1955	1960-1965	1970-1975	1980-1985	1990-1995	2000-2005	2005-2010
Developed countries	66	69,8	71,3	72,9	74,1	75,8	77,1
Developing countries	41,7	48,6	56,6	61	63,9	66,6	67,7
The poorest countries	36,4	40,6	44,4	48	50,4	54	55,9
World	46,6	52,4	58,2	61,7	64	66,4	67,6
Source : United Nations Population Division							

Global life expectancy has increased by 50% since 1950 to 70 years

Infant mortality rates have significantly improved in all regions of the world

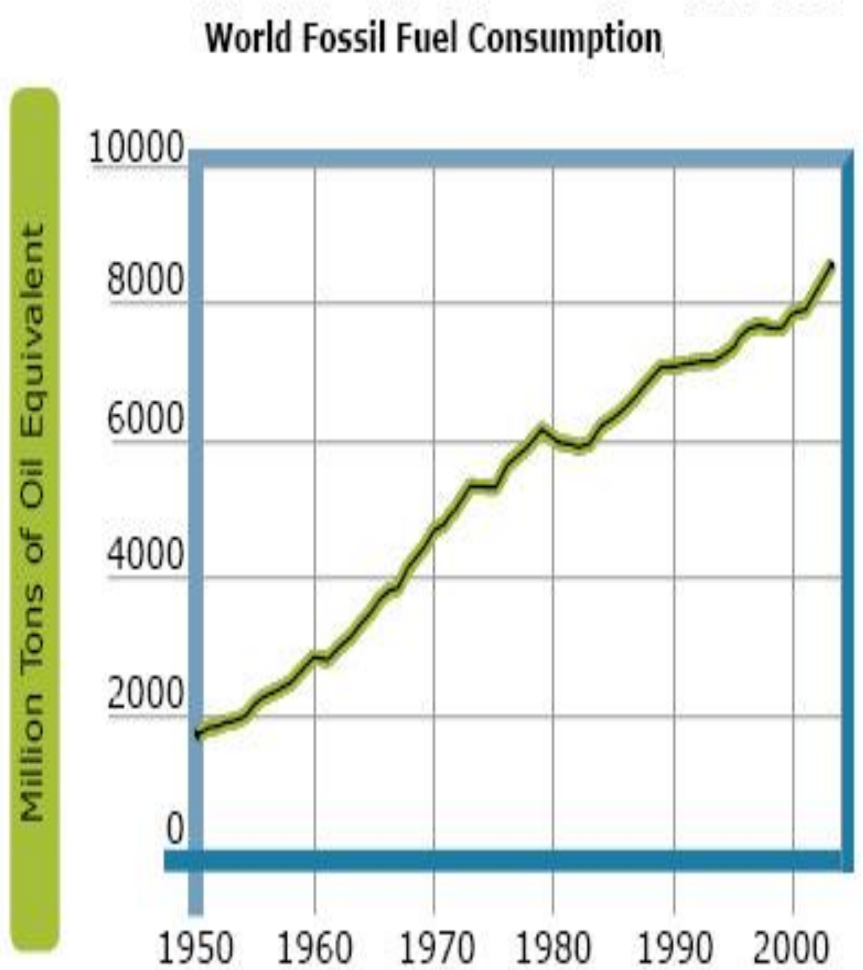


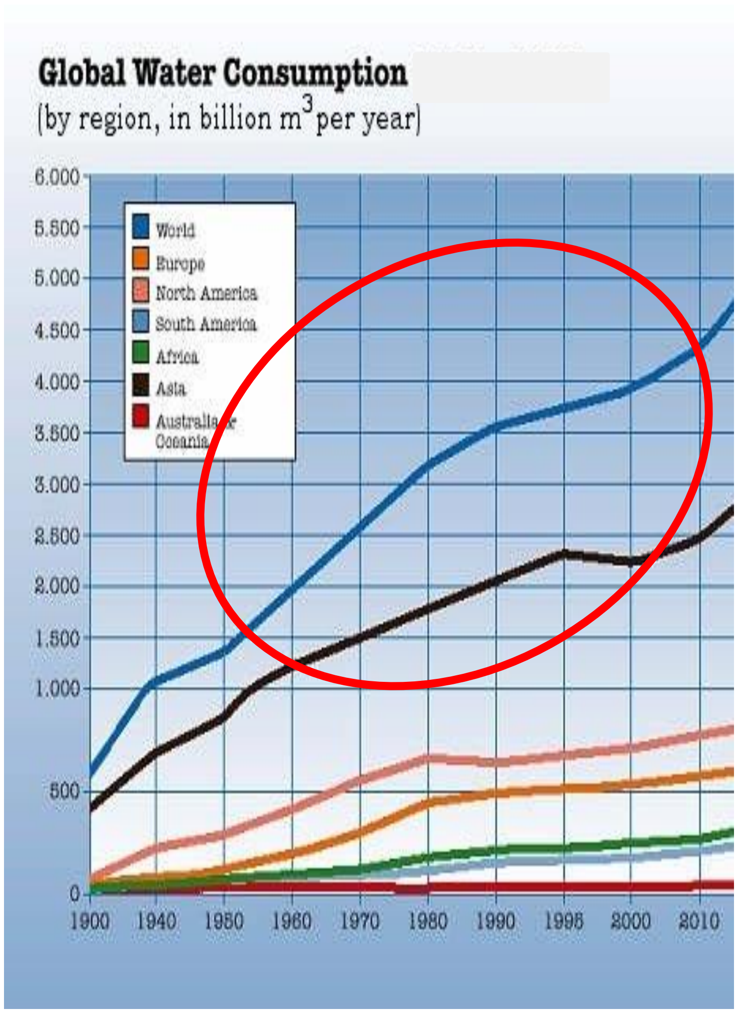
Consequences: population



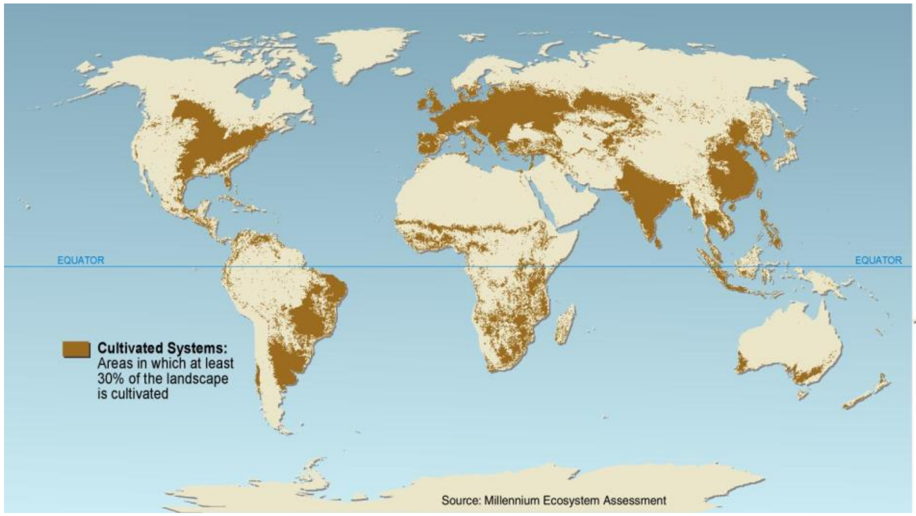
The global population more than doubled in size from 3bn in 1959 to 7bn in 2011

Consequences: resource consumption



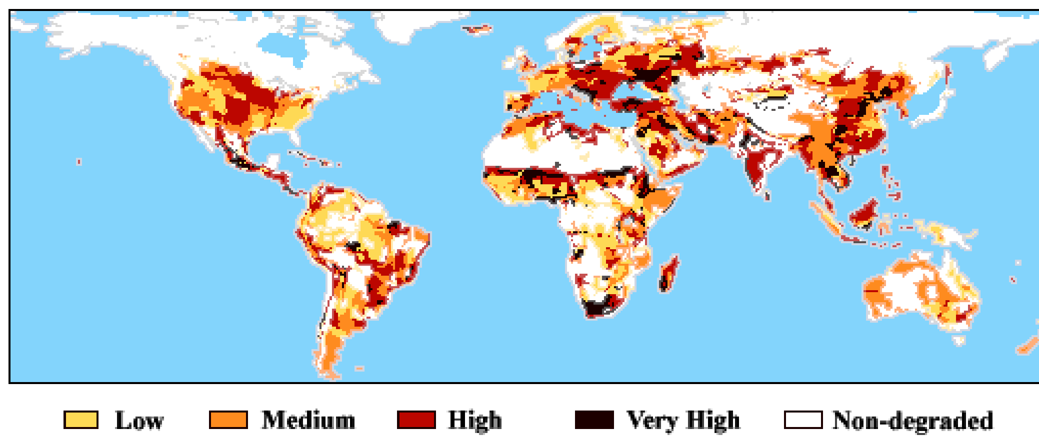


Consequences: land use change



- More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850
- In 2000 cultivated systems cover 25% of Earth's terrestrial surface

- An estimated 23% of all usable land is degraded
- 20% of the world's pasture and rangelands have been damaged
- 580m ha of forests have been degraded by logging and clearance, nearly 40% of this since 1975



PROJECTION: Geographic
SOURCES: UNEP/ISRIC

UNEP
EAD/GRID-Geneva

Source: Millennium Ecosystem Assessment, UNEP

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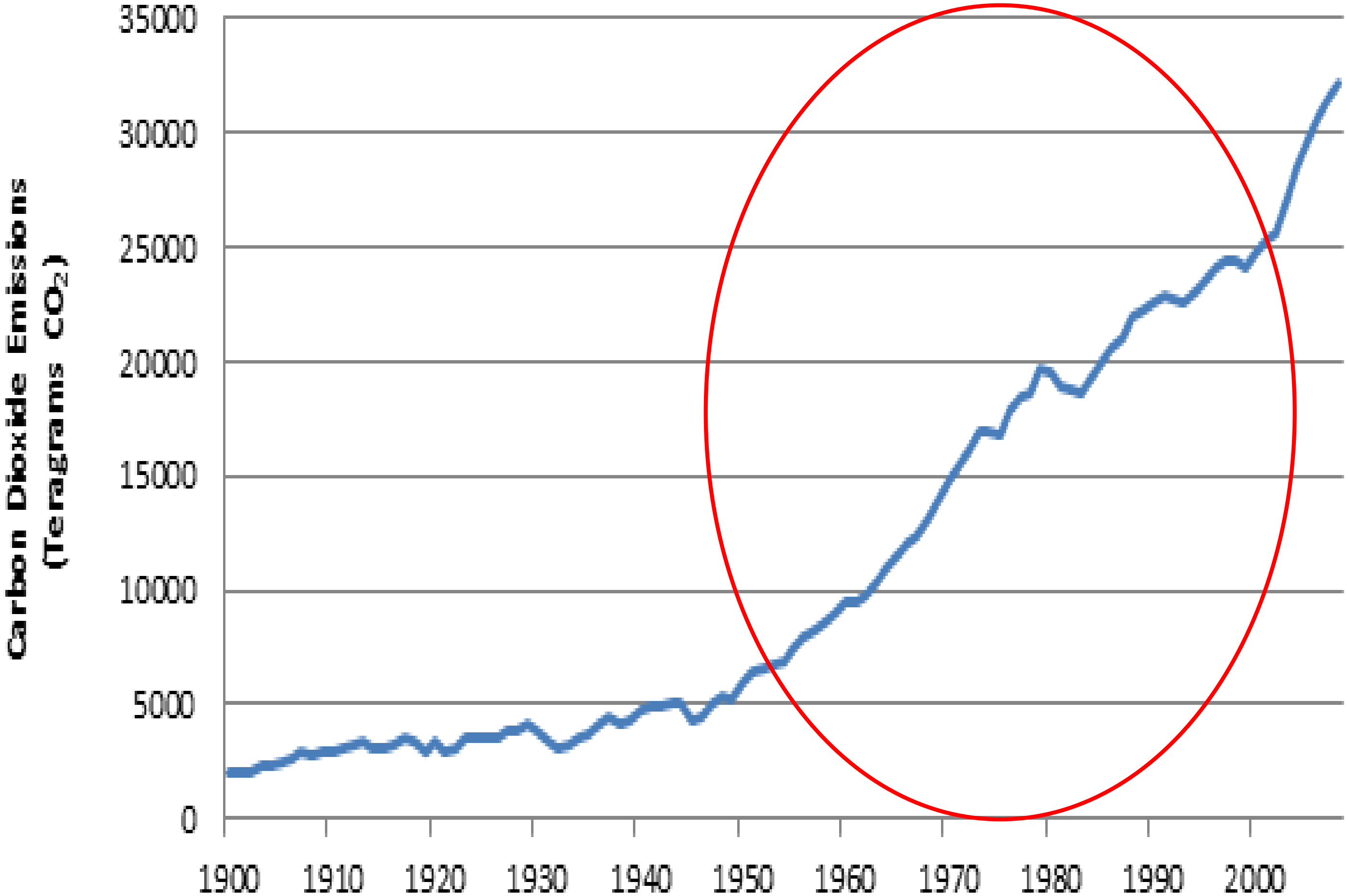
Consequences: emissions

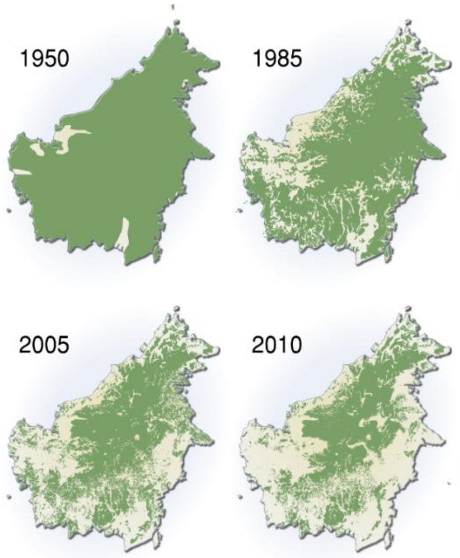
Carbon dioxide emissions (in teragrams CO2)



60% of the increase in the atmospheric concentration of CO_2 since 1750 has taken place since 1959

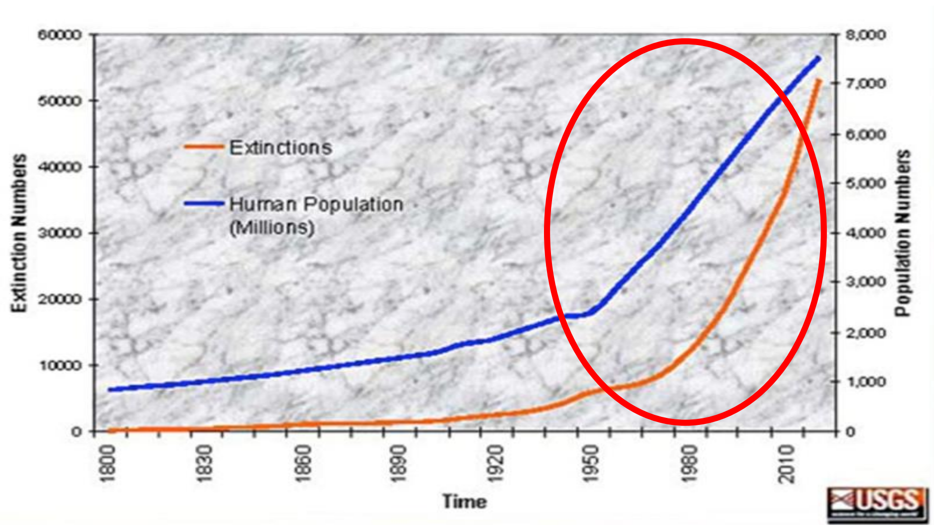
Consequences: ecosystems

Forests

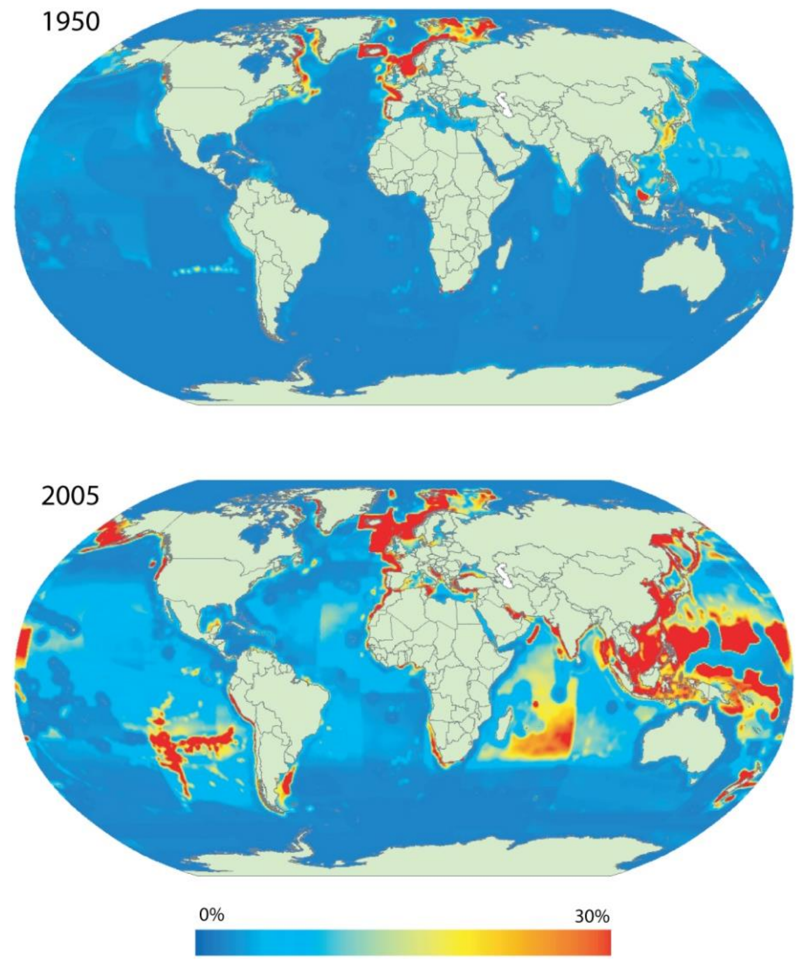


Forest cover degradation, Borneo

Extinction numbers:



Seas



The pace of fisheries expansion, quantified by PPR, the Primary Production Required to generate the catch of fisheries, as a proportion of local primary production (Swartz et al, 2010)

Where has the 20th Century left us?

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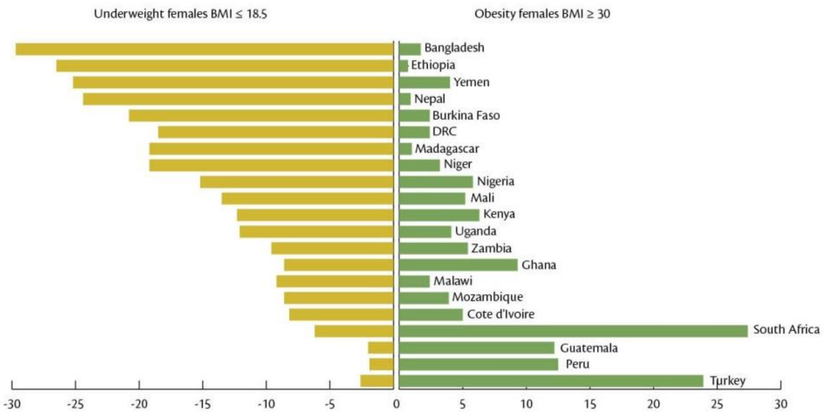
There is less poverty, but more food inequality

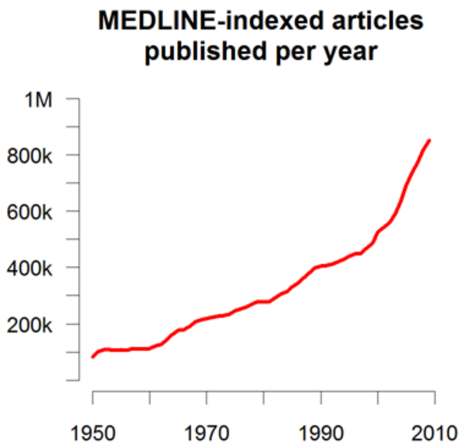
- ~1.3bn still live below the poverty line ($1.25/day)
- 1 in 4 children worldwide are stunted
- In 2008, 35% of the world population was overweight, and 29% was micronutrient deficient



Source: GloPlan, 2014

Industrialisation, globalisation and urbanisation have led to significant greenhouse gas emissions

We are more informed than ever before



There are major natural and physical resource pressures

In key ways, the early 21st Century is already determined…

The global community will have to contend with a number of significant challenges

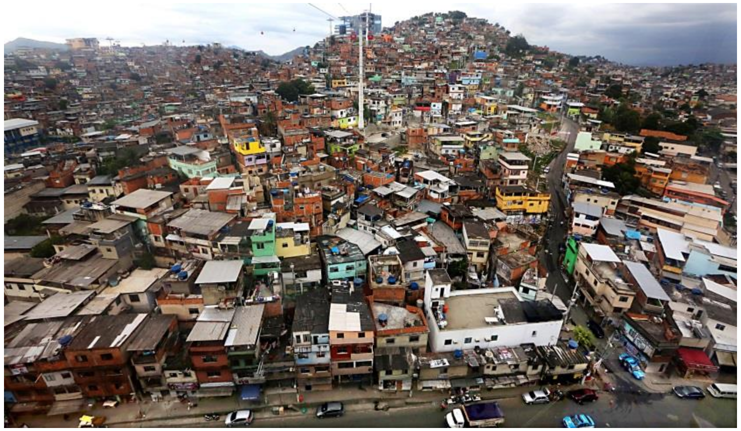
Consumption will increase with prosperity

Demographic momentum:

An extra billion people by 2025

Urbanisation:

global urban:rural ratio ~58% by 2025



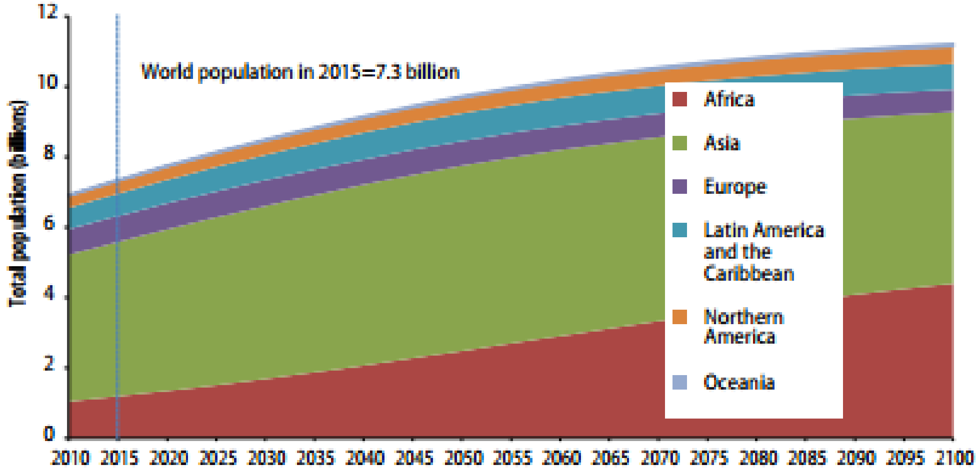
Alemao Shanty Town, Brazil
Brazil is forecast to have 90% urbanisation by 2020
33% of the world's urban population live in slums

Climate change:

GHG in the atmosphere <u>now</u> will drive changes up to 2030

Global Population Predictions

World population by major area, 2010-2100



Source: World Population Prospects 2015, UN

More than half of global population growth between now and 2050 is expected to occur in Africa: of the additional 2.4bn people projected to be added to the global population between 2015 and 2030, 1.3bn will be added in Africa

Historical progression of Global Population

Total Population	Year	Interval
3 billion	1959	
4 Billion	1974	15 years
5 Billion	1987	13 years
6 Billion	1998	11 years
7 Billion	2011	13 years
8 Billion	2022	11 years
9 Billion	2040	18 years
10 Billion	2055	15 years

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Urbanization Trends

- 54% of the world's population live in urban areas, versus 30% in 1950
- By 2050 66% of the world's population is projected to be urban
- Nearly half of the world's urban dwellers live in relatively small cities of less than 500,000 inhabitants. Around 1 in 8 live in 28 mega-cities with more than 10m inhabitants (UN, 2014)

"Urbanization in Asia"
UN Photo/Kibae Park

The changing global poverty landscape and the rise of the global middle class

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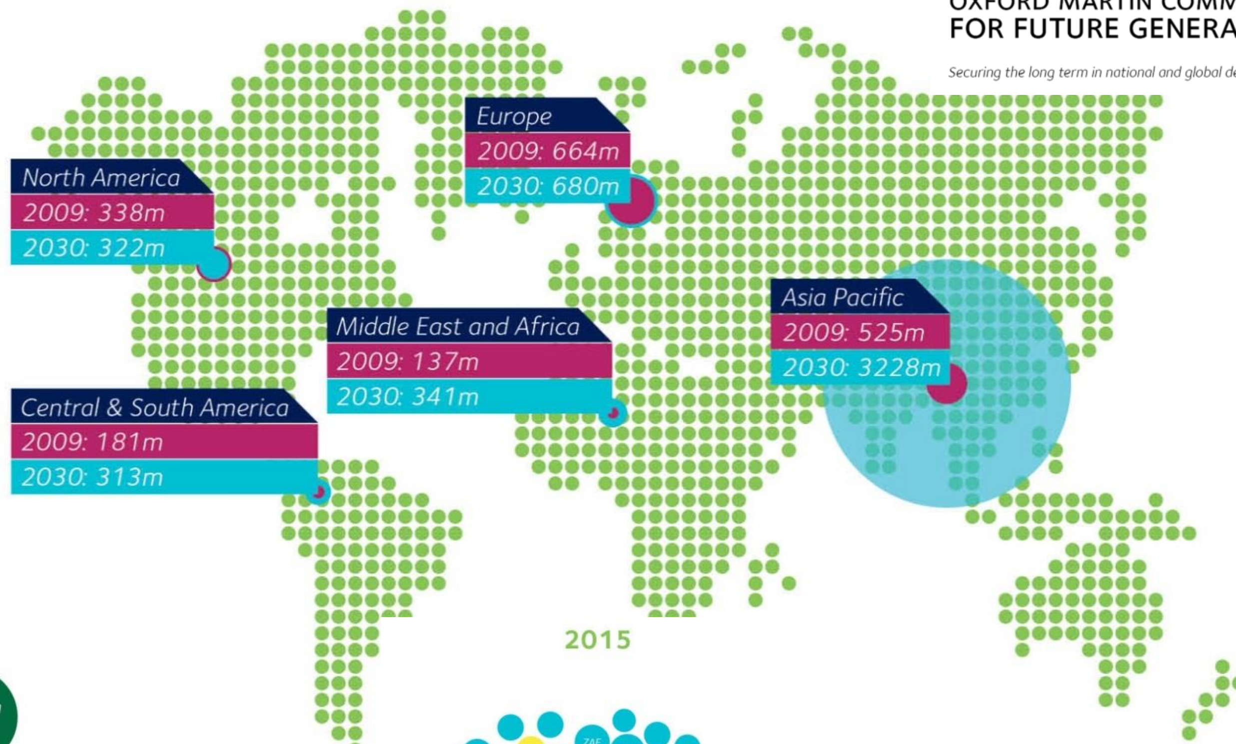
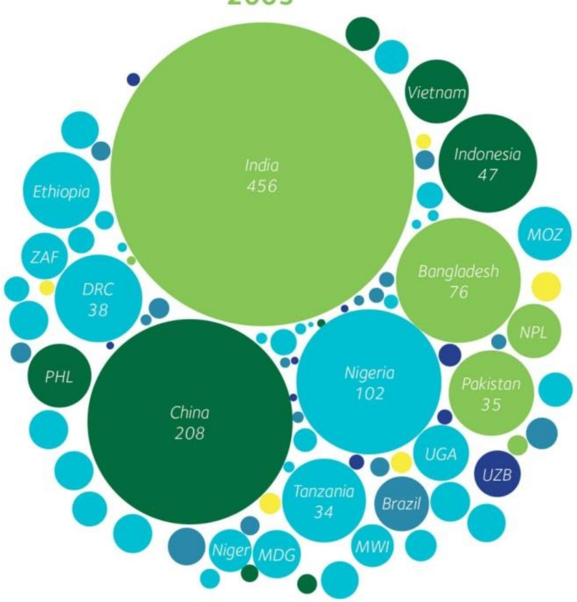
Securing the long term in national and global decision making

Number of households with daily expenditures $10-100, in millions

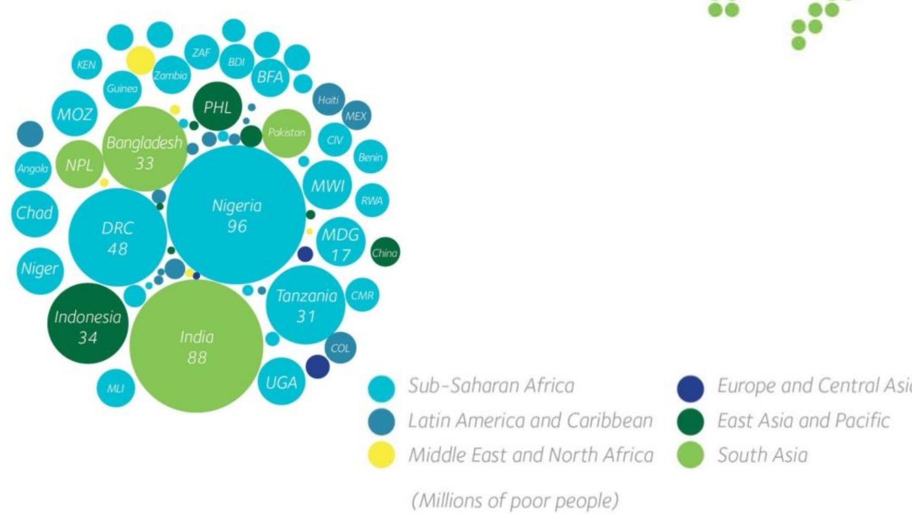


Numbers of individuals living below $1.25/day, in millions

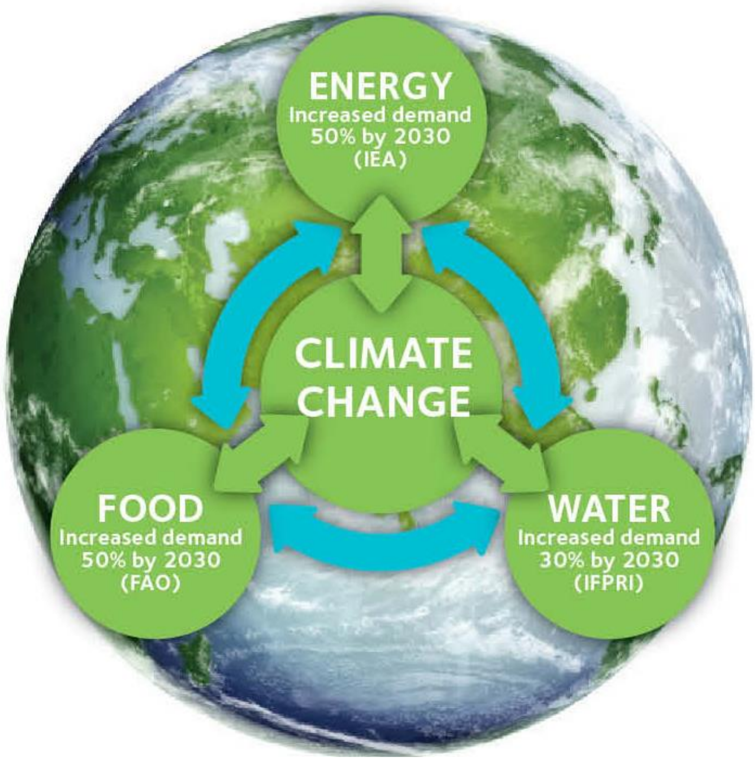
2005



2015

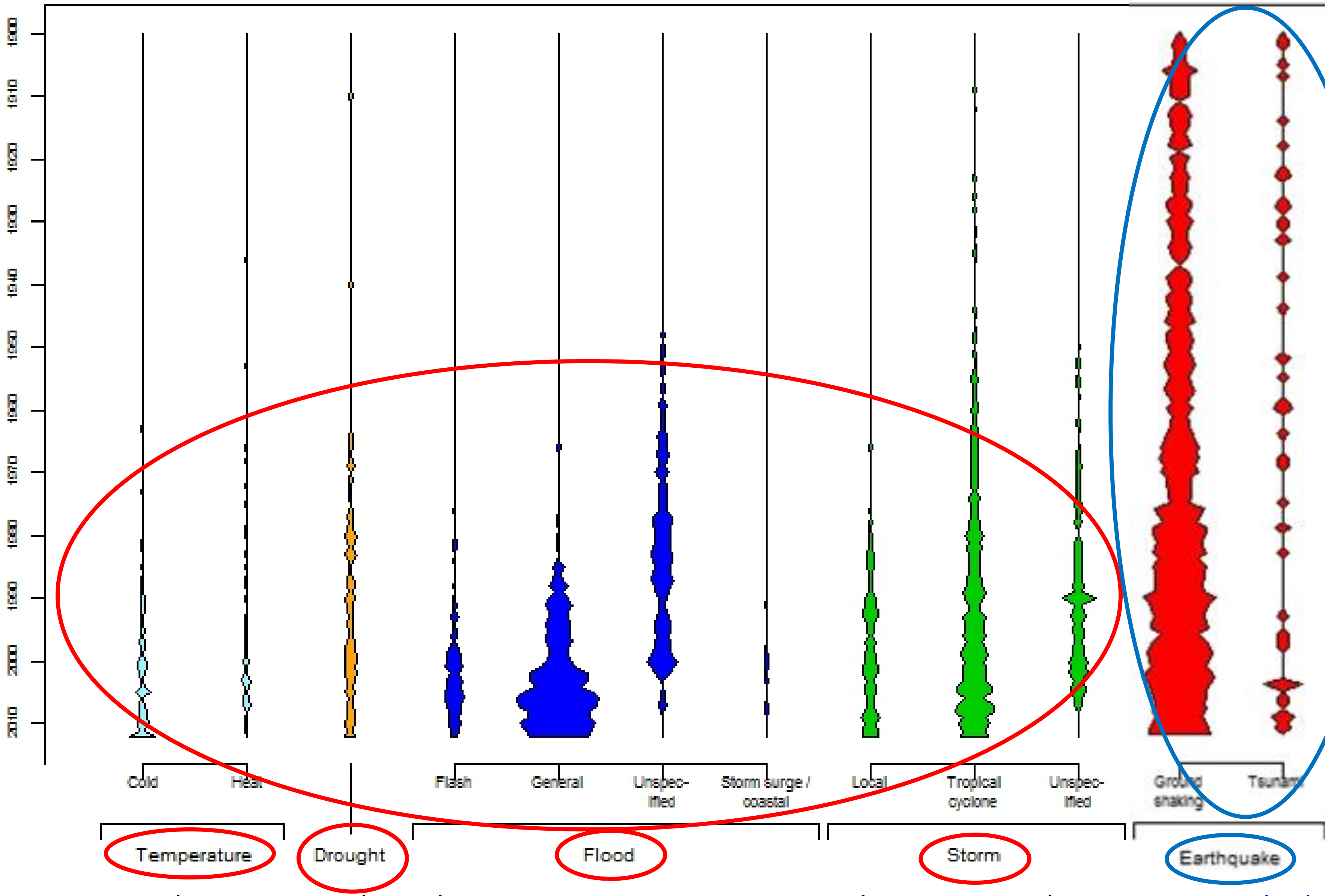


The "perfect storm": food, water and energy



Source: Professor Sir John Beddington, *Biodiversity: Policy Challenges in a Changing World London: Government Office for Science, 2009*

Number of natural disasters 1900-2012



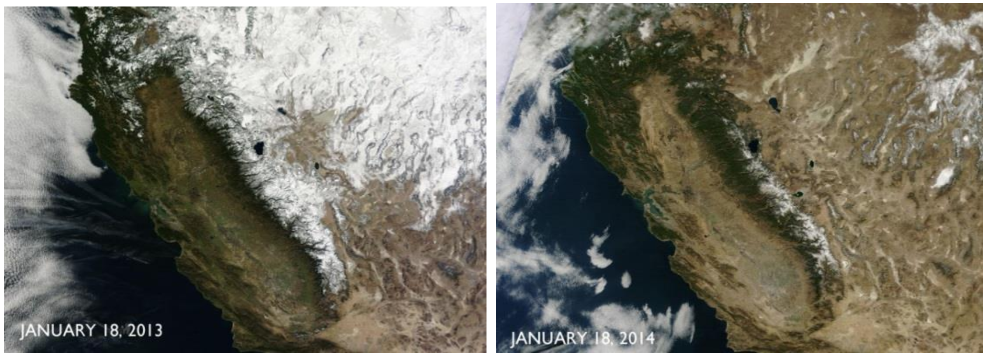
Source: D. Guha-Sapir, R. Below, Ph. Hoyois - EM-DAT: International Disaster Database – www.emdat.be

Natural Disasters and Attribution

- 1970-2008: over 95% of deaths from natural disasters occurred in developing countries
- Global damage from natural disasters steeply increased from $36bn pa 1985-1994 to $142bn 2005-2014 (Guha-Sapir, Below & Hoyois, 2015)
- Detailed studies of both European summer heatwaves & wintertime droughts 1902-2010 found that anthropogenic climate change magnified likelihood of those events (Stott, Stone & Allen 2004, Hoerling et al 2012)
- Links have been established between Californian heat waves & global mean temperatures (Nuccitelli, 2014), and between increases in heatwaves and climate change (Coumou & Rahmstorf, 2012)
- Studies have shown an intensification of precipitation events in the Northern Hemisphere with climate change (Min et al, 2011)
- The risk of the England & Wales floods in Autumn 2000 was 20% higher thanks to climate change (Pall et all, 2011)
- Doubling of atmospheric CO_2 concentrations will triple number of Cat 5 storms (Anderson & Bausch, 2006)



US Drought, 2013-2014

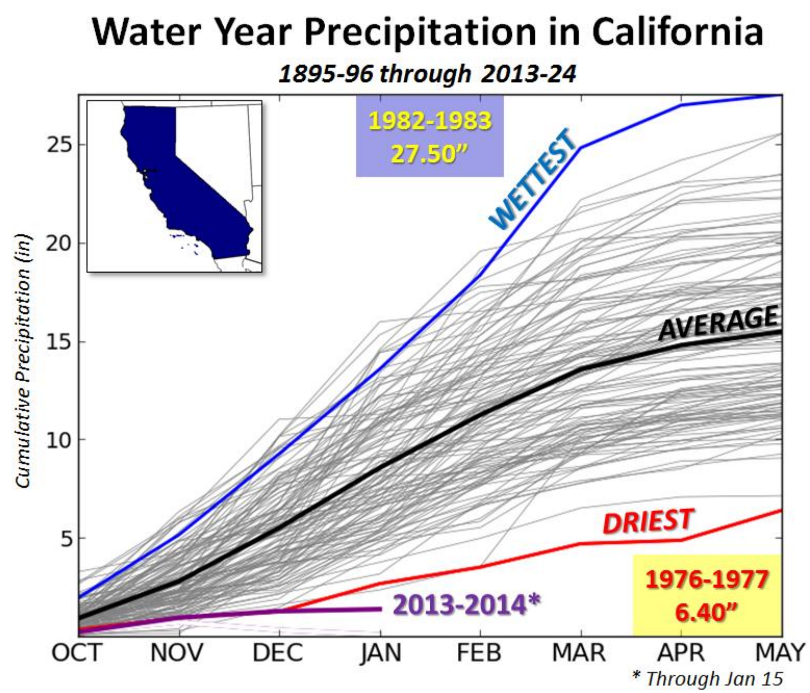


Snow cover decline in Sierra Nevada Mountains

Lake Mendocino

California: 665 wildfires in 2014 vs historical average of 225

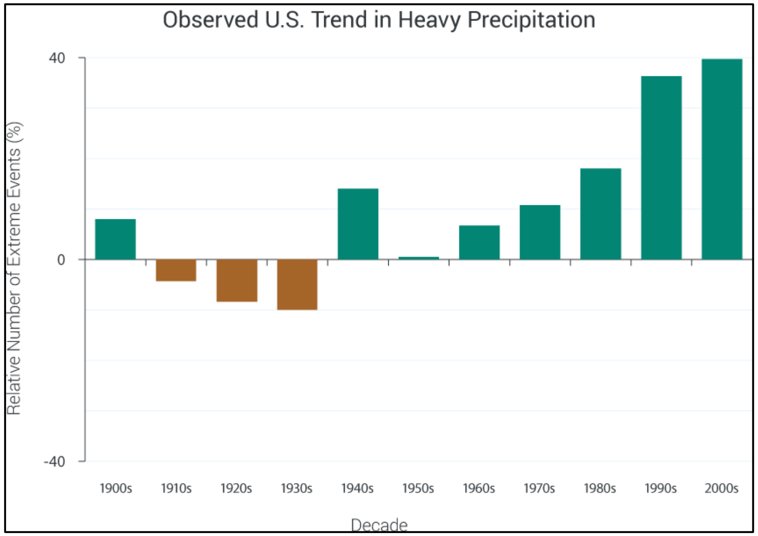
Obama administration has announced it has set aside disaster funds for 'mega-fires' across western states



Extreme rainfall and climate change

- Simple thermodynamics (the Clausius-Clapeyron equation) holds that warmer air holds more water, so it is to be expected that global warming will lead to heavier short term rainfall events
- Studies show that the median intensity of extreme precipitation increases at 5.9-7.7% per degree of near-surface temperature (Westra et al, 2013)
- Historical data (below right) and simulated models (below left) suggest that the intensity of rainfall patterns will increase

Regional climate models indicate that with global warming, north-west England could see very large increases in extreme rainfall intensity – up to 60% (Fowler et al, 2009)



UK, December 2015: wettest on record

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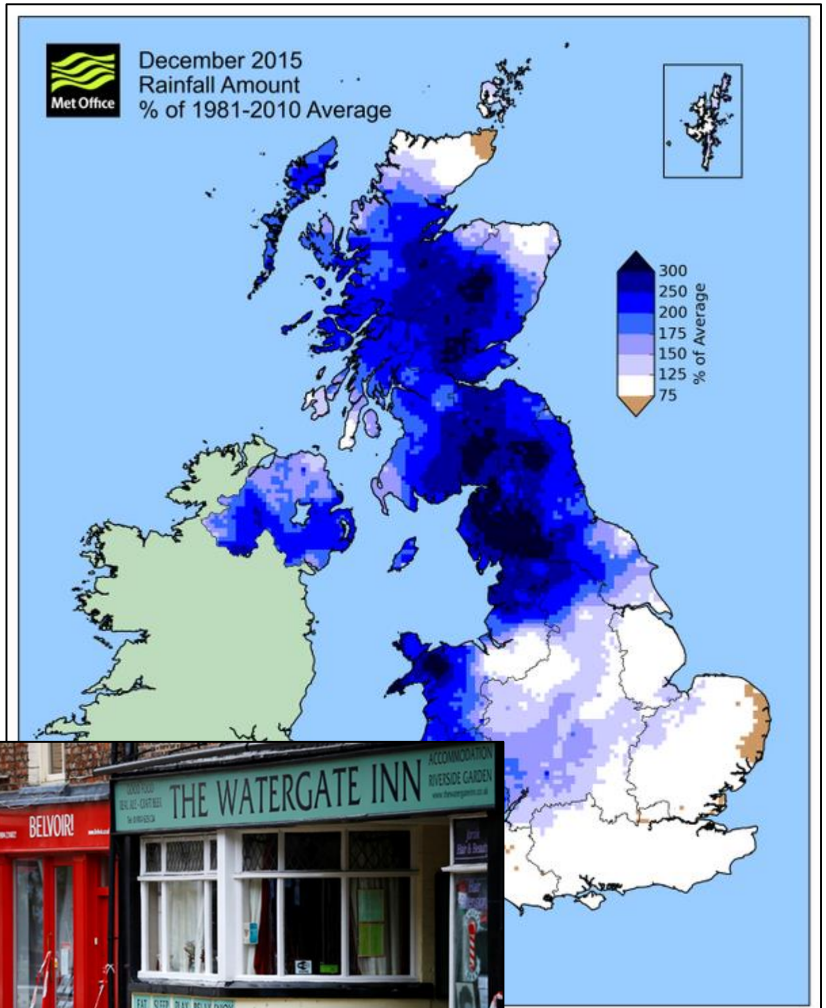
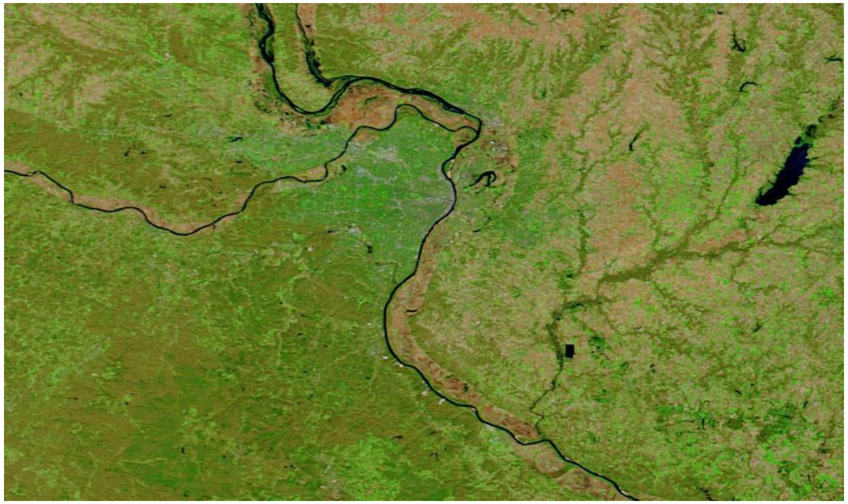


Latin America Flooding: over 150,000 people displaced

Paraguay, Argentina, Uruguay and Brazil all affected

Flooding in Southern States, US

Central Mississippi River Valley,
Missouri/Illinois



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The 2015/2016 El Nino:
likely to be the strongest on record

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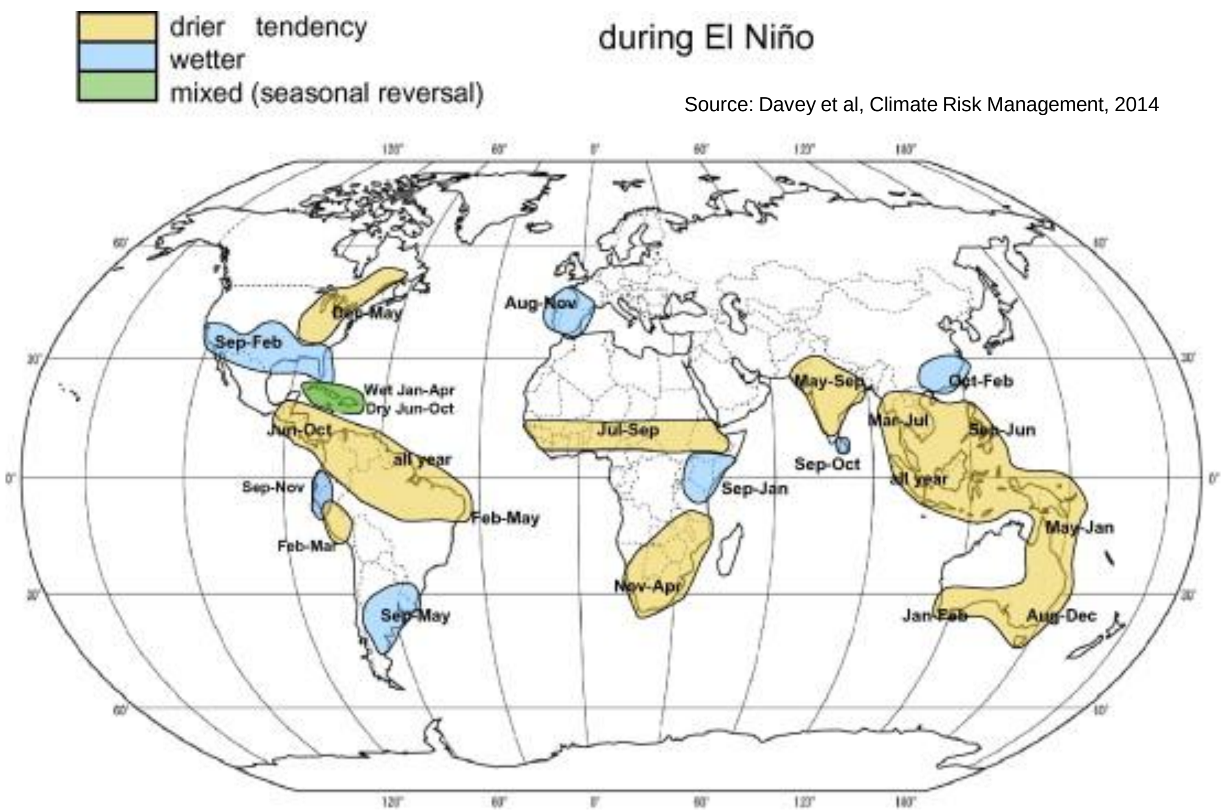
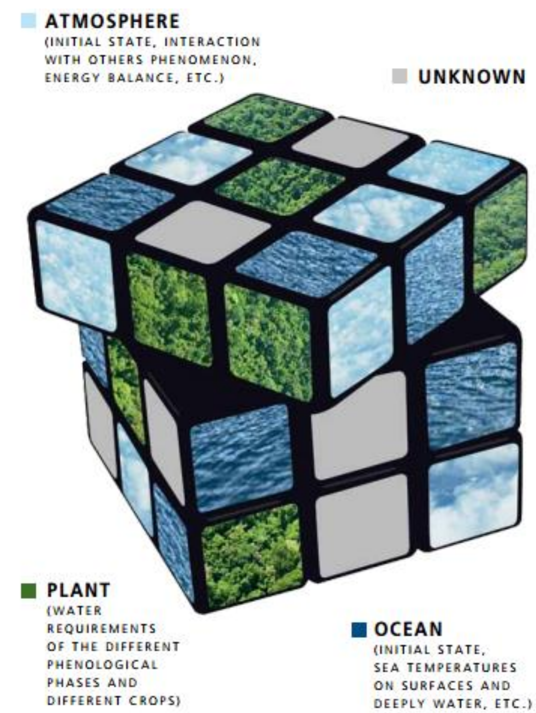
- El Nino and La Nina historically occur approximately every 5 years
- An El Nino event substantially shifts the likelihood of particular conditions



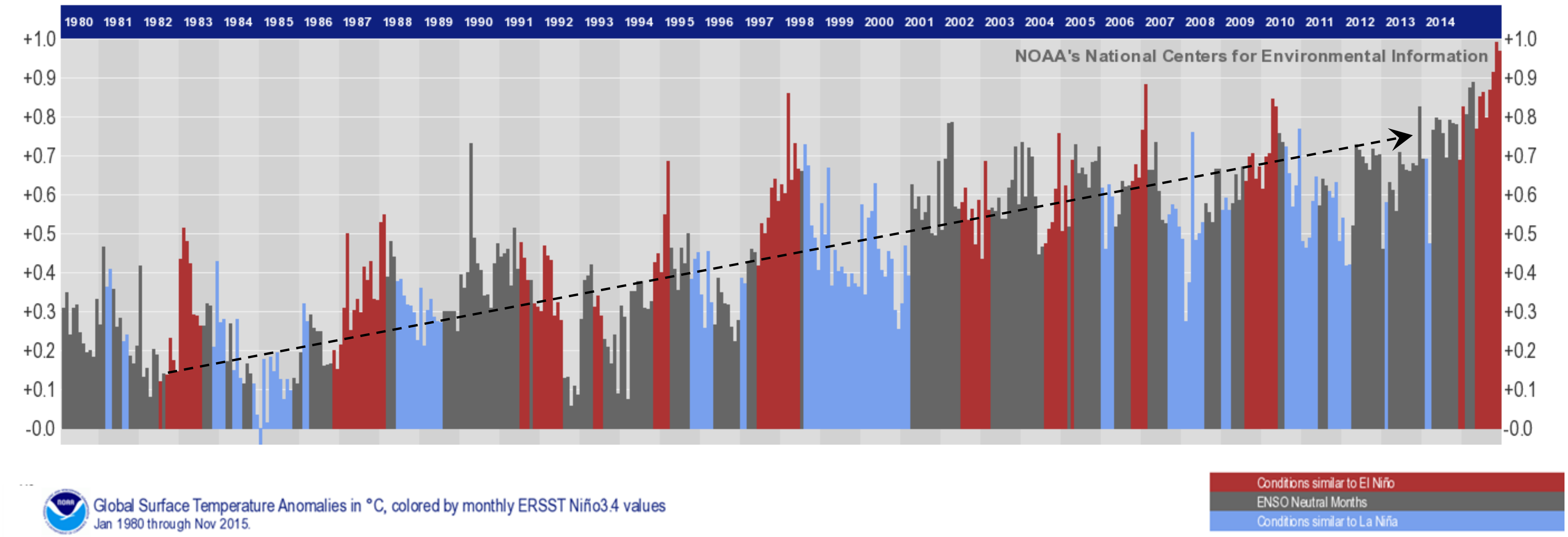
Source: Davey et al, Climate Risk Management, 2014



It is often the poorest parts of the world that are impacted – as well as those exposed to climate change

- Successive poor rains in Ethiopia with 4.5m people needing food aid
- Maize output in Malawi reduced by 25%, with 2-3m people needing food aid
- Maize output in Zimbabwe reduced by 35% with 1.5m people needing food aid
- A 2 year drought in Central America
- A reduced Indian monsoon reduced, raisings odds for 2016 drought in East Asia

Extreme El Ninos in a warmer climate

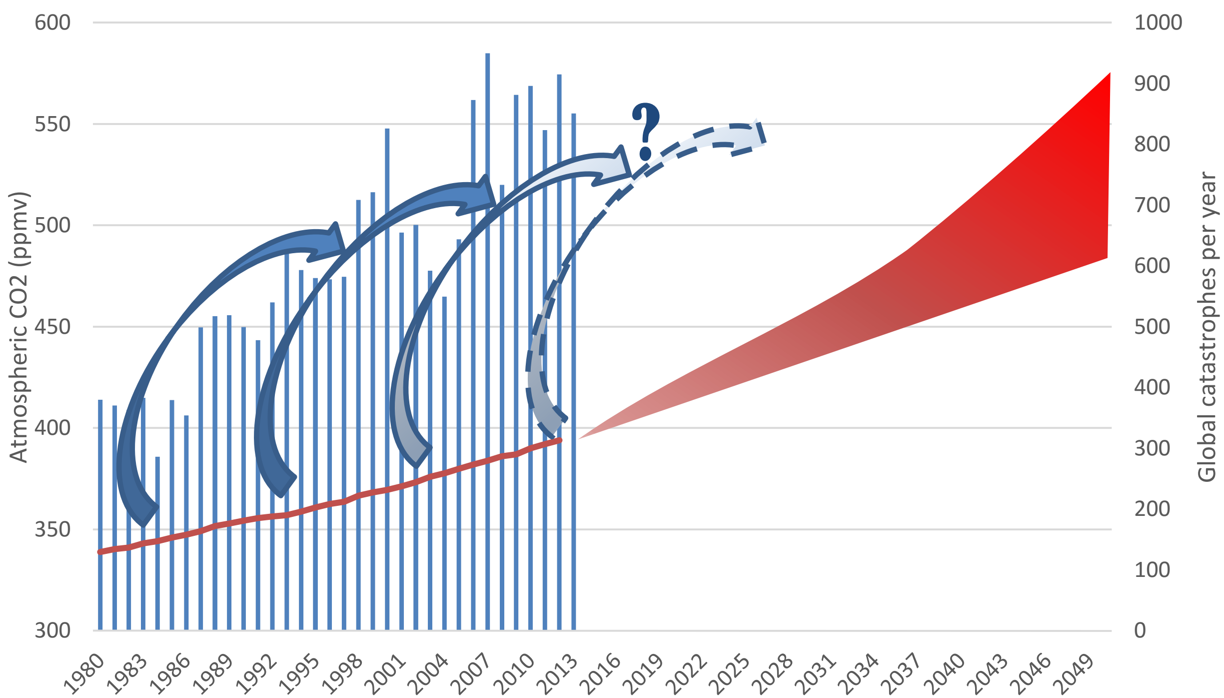


- Extreme El Ninos tend to occur once every 20 years, and extreme La Ninas once every 23 years. These are significant global risk events: for example the extreme El Nina of 1998 displaced 200m people in China, submerged half the land mass of Bangladesh, and caused a violent North Atlantic hurricane season
- Extreme El Ninos and El Ninas are predicted to double in frequency under climate change (Cai et al, 2014)
- "The last big El Nino was 1997-1998. The planet has changed a lot in 15 years. We have had years of record Arctic sea ice minimum. We have lost a massive area of northern hemisphere snow cover, probably by more than 1 million square km in the past 15 years…this is a new planet….we have no precedent" David Carlson, Director, World Climate Research Programme

Emissions of twenty years ago are dictating today's climate, and thus could be dictating today's severe weather patterns

So what will happen to the weather of the near future, given the recent rapid increases in emissions?

And what will happen to the weather of the far future, given the next fifty years of emissions?



Number of natural disasters per year, as recorded by Munich Re

Atmospheric carbon dioxide concentrations (ppmv), as measured by the IPCC

Reference carbon dioxide concentration scenarios, as projected by the IPCC

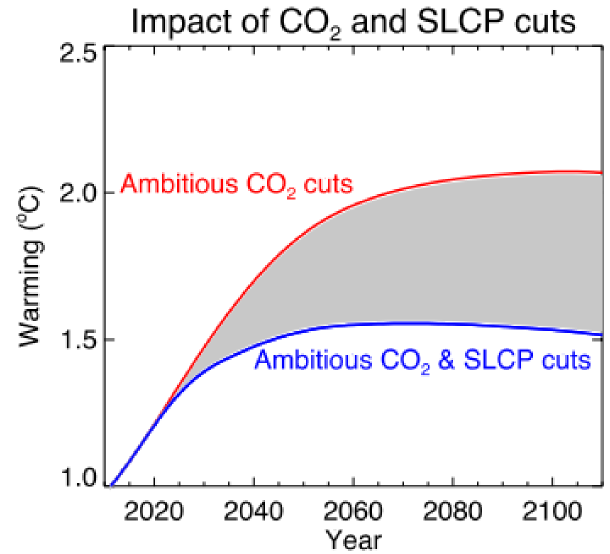
COP Paris 2015: 21 years of negotiations

- Outcomes:
  - An agreement to limit temperature rises to “well below 2^{o}C” and efforts to limit rises to 1.5^{o}C
  - A long term emissions goal to peak global emissions “as soon as possible” and to achieve ‘balance’ between emissions and sinks in the second half of the century, i.e. reaching net zero after 2050
  - A legal obligation on developed countries to continue to provide climate finance to developing countries
  - A five year review cycle on national targets, with ratchet mechanisms to maintain progression
- There were no quantified targets on the size or timing of emissions cuts to meet these goals, but this reflects the pragmatic nature of the deal
- 188 countries have made pledges which cover 99% of global emissions and will cost an estimated $3.5trn to implement
- The pledges alone will not limit warming to 2^{o}C but have political significance beyond the numbers:
  - EU: at least a 40% reduction in greenhouse gases by 2030 compared to 1990 levels
  - US: 26-28% domestic reduction in greenhouse gases by 2025 compared to 2005 levels, including the land sector & excluding international credits
  - China: a peak in CO_2 emissions, 20% of energy from low-carbon sources, and emissions per unit GDP cut to 60-65% of 2005 levels, all by 2030

Is it feasible?

- Past emissions, of ~2tn tonnes of CO2, already commit us to around 1^{o}C of warming.
- In order to make the 1.5^{o}C target, and considering only CO2, net future emissions will have to be limited to another 1tn tonnes of CO2

- To deliver 1.5^{o}C, it will be necessary to take immediate action on not only CO2 emissions but also on SLCPs (short-lived climate pollutants)
- The 1.5^{o}C target also requires the rapid deployment of industrial-scale CO2 disposal such as CCS on fossil fuel and biomass energy plants

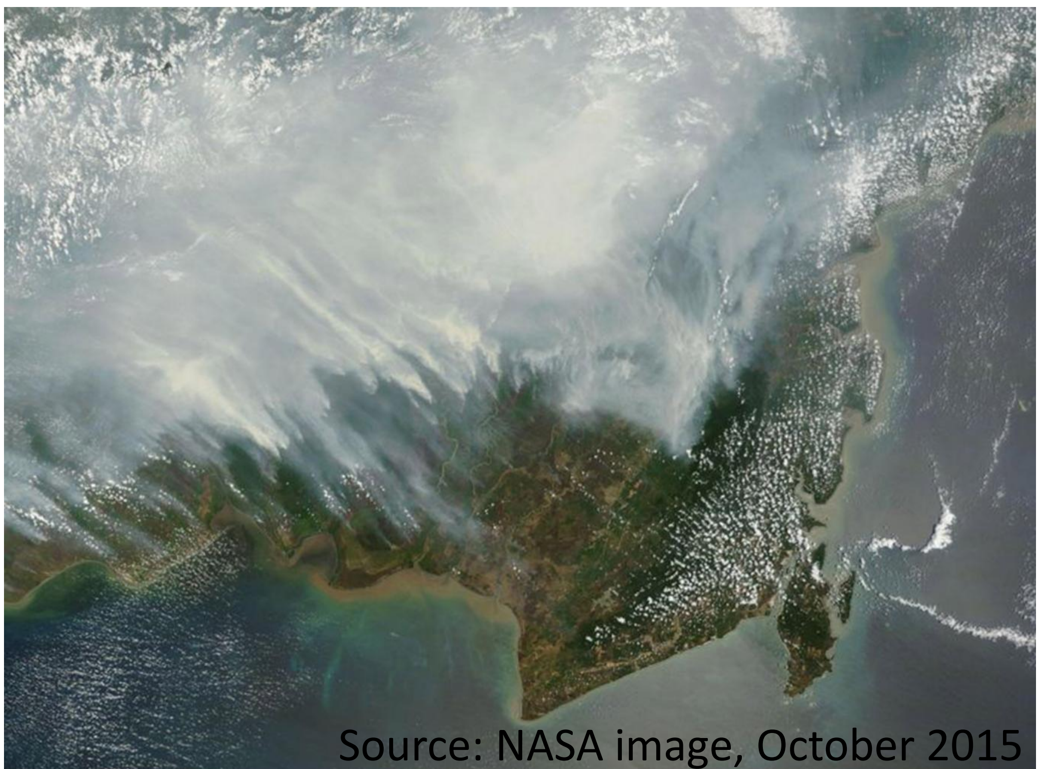


Source: Professor Myles Allen, 2015

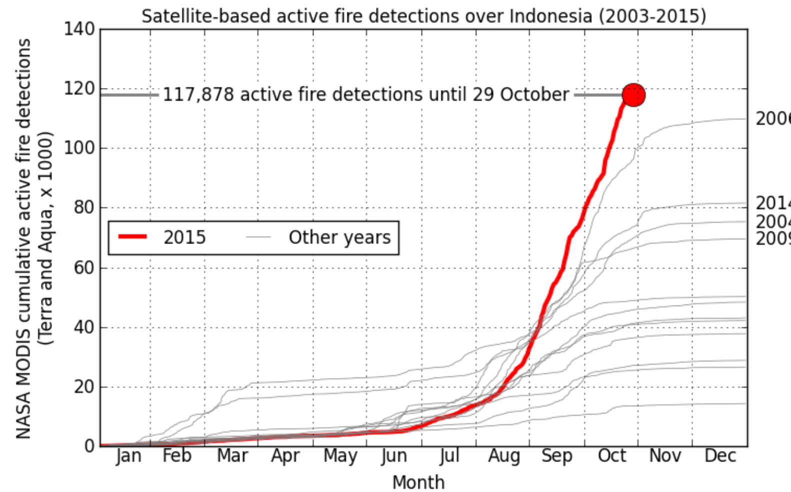
Prof Michael Grubb of UCL: "All the evidence from the past 15 years leads me to conclude that actually delivering 1.5^{o}C is simply incompatible with democracy"

Responsible Action: Countries

- In 2015 Indonesian peat fires, mostly resulting from illegal slash and burn clearance techniques and spreading thanks to the El Nino dry conditions, released 1.6bn tonnes of greenhouse gases – as much as the combined contribution of Canada and Germany in 2012
- On some days daily emissions from peat fires have exceed those from the US economy

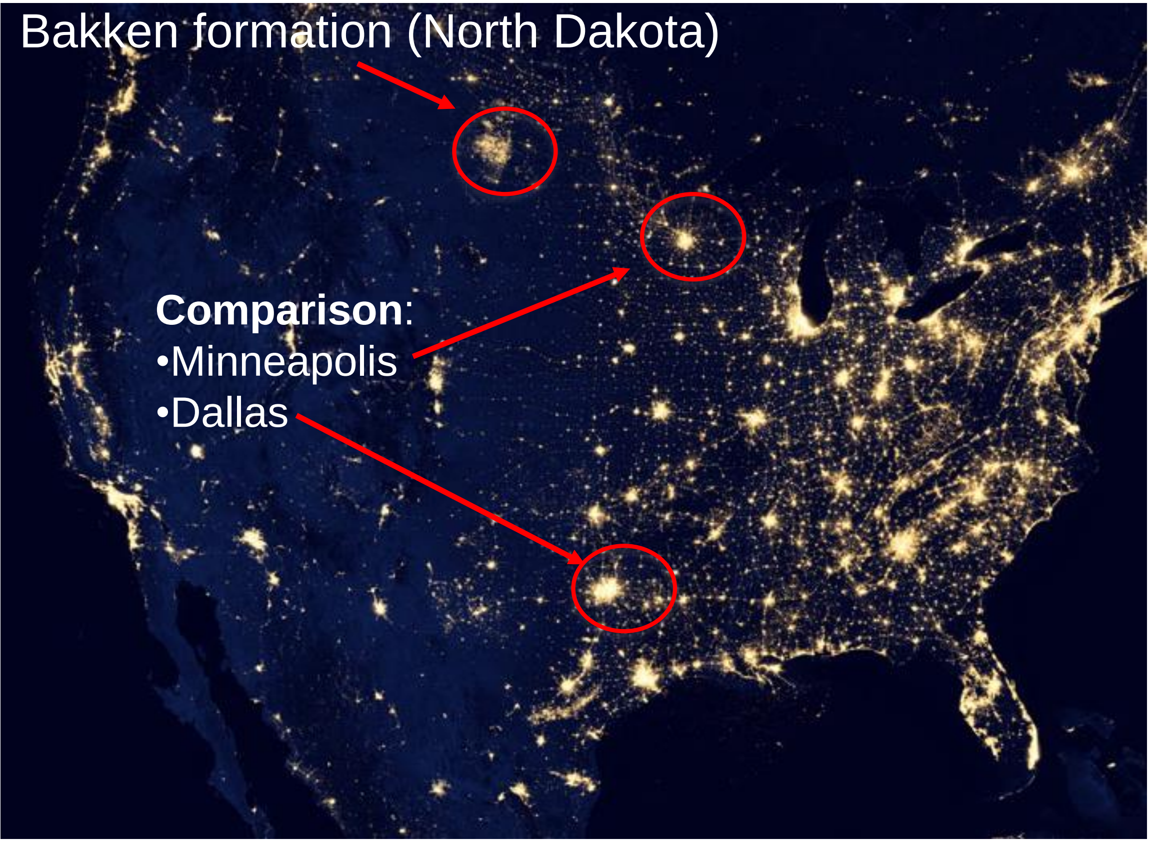


Source: NASA image, October 2015

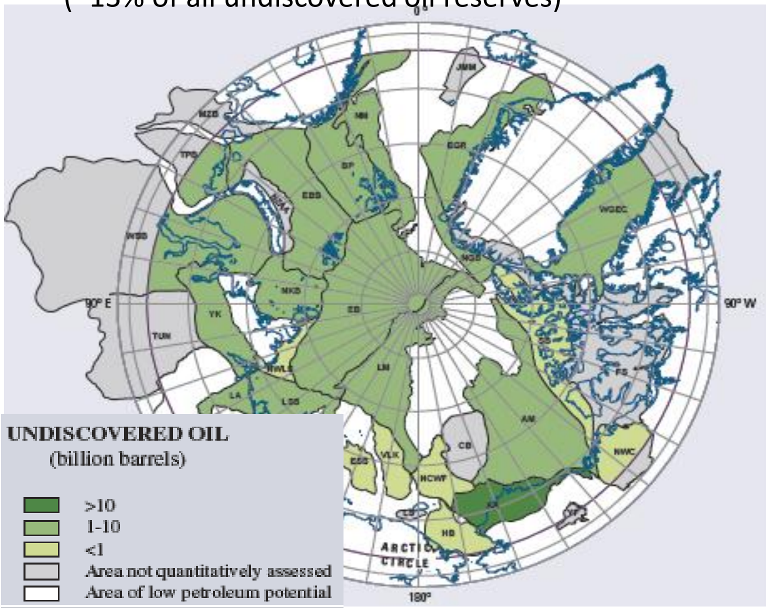


Source: Global Fire Emissions Database

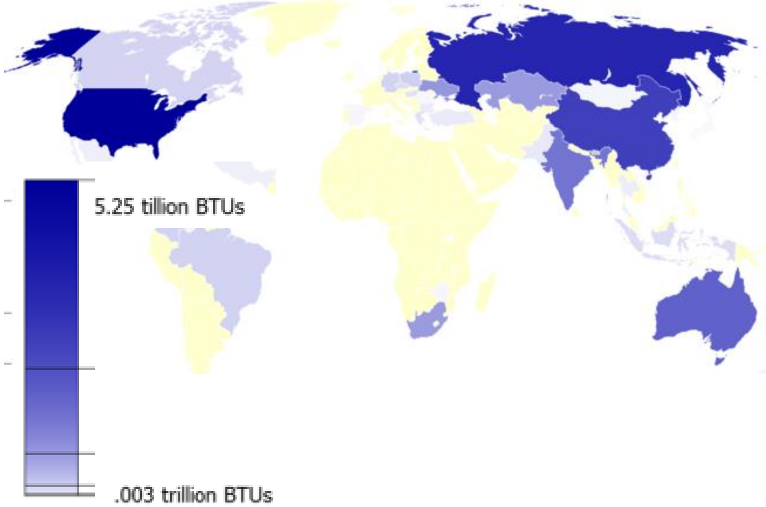
Responsible Action: Companies



US Geological Survey: 90m barrels of oil (~13% of all undiscovered oil reserves)



Coal Reserves (10^{12} BTU)



These resources can only be used responsibly with carbon sequestration techniques

CHALLENGE: World Energy Requirements

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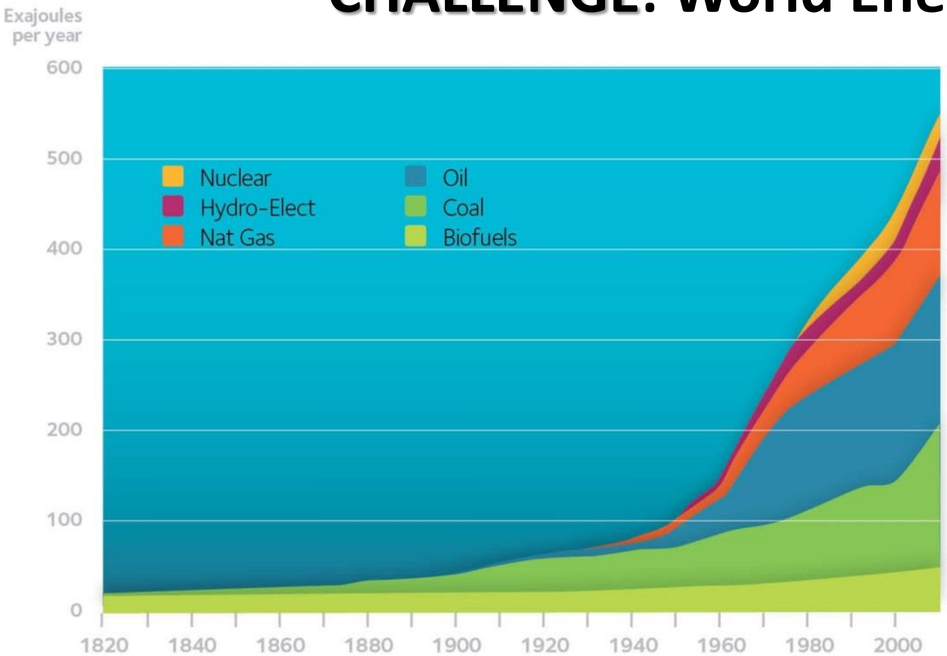
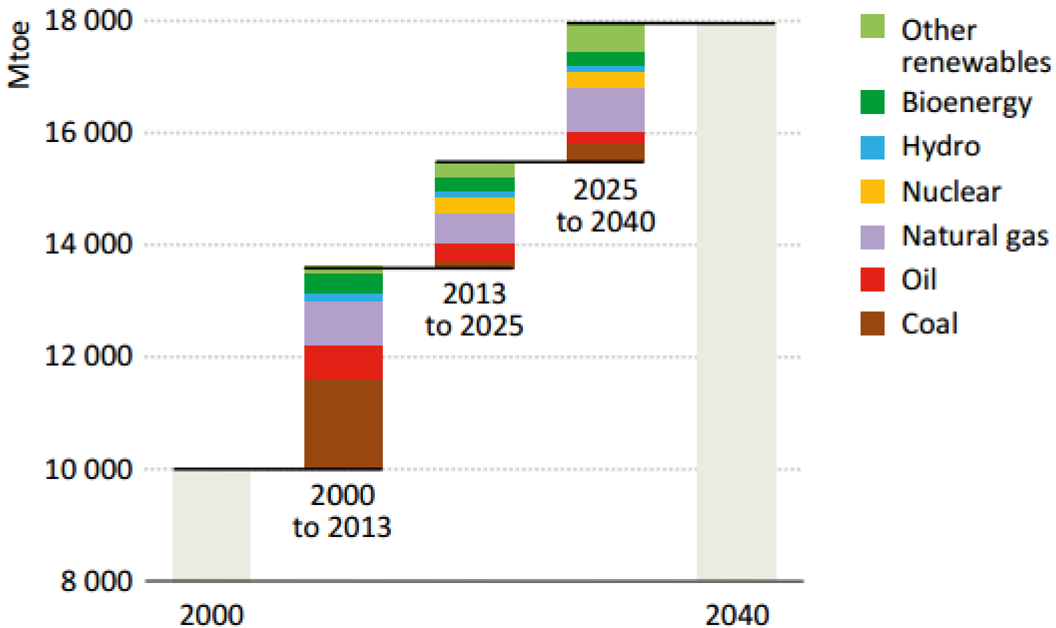
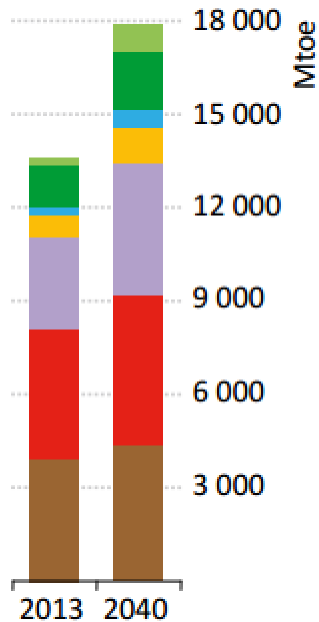


Energy demand is expected to increase by 32% by 2040, with global electricity demand growing by over 70%

Renewables are expected by the IEA to overtake coal as the largest source of electricity by the early 2030s





Emerging market energy use and climate change

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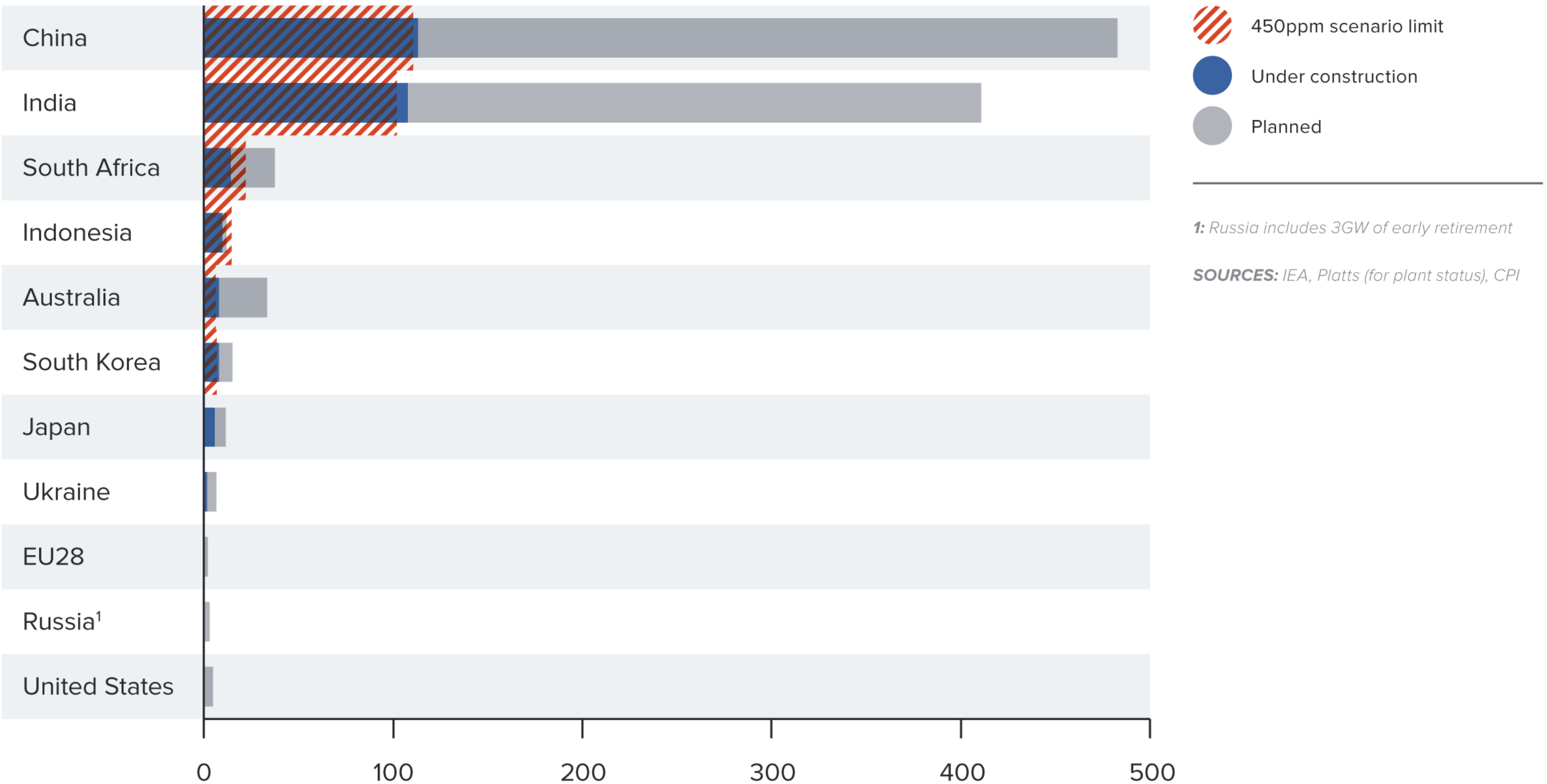
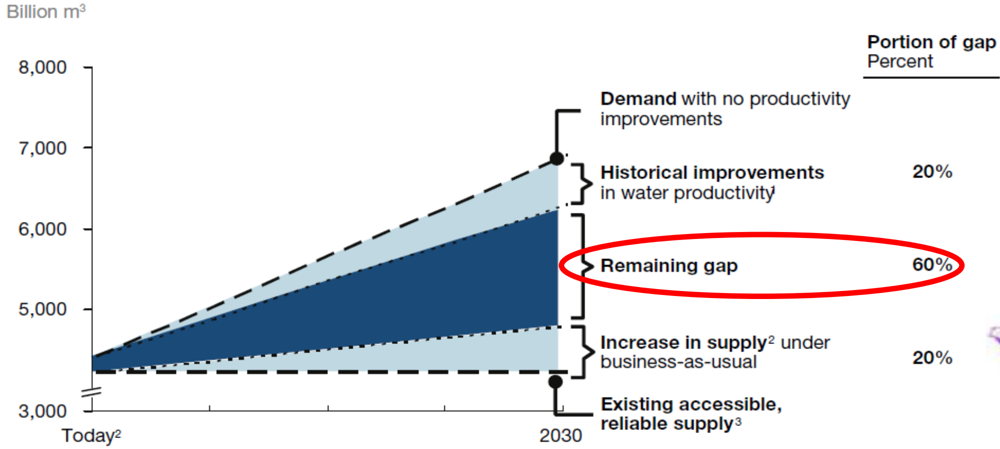


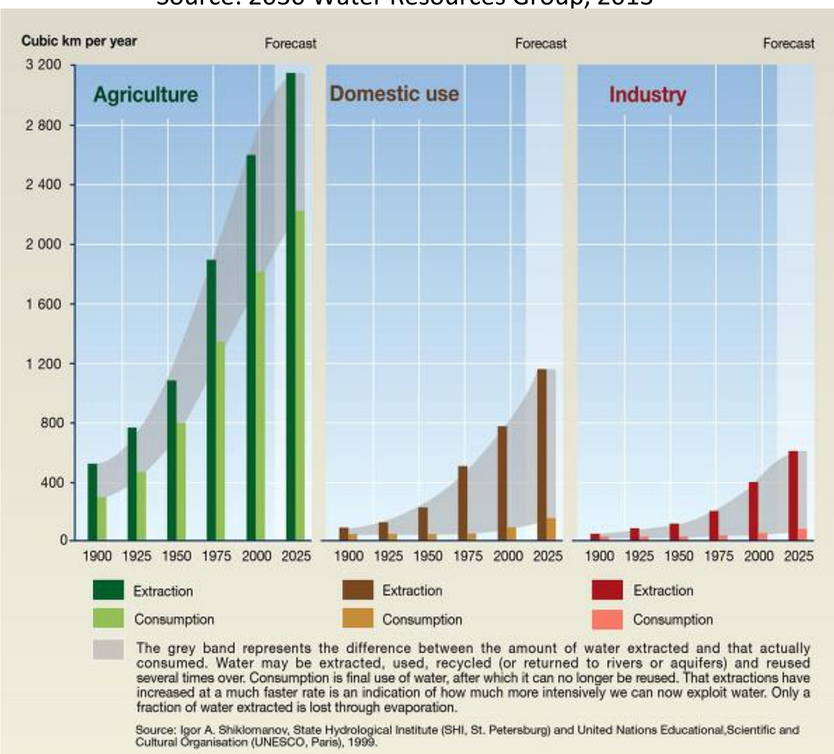
Coal-fired power plants under construction and planned,

versus IEA 450ppm CO_2 scenario (equivalent to $2^{o}C$ temperature rise)

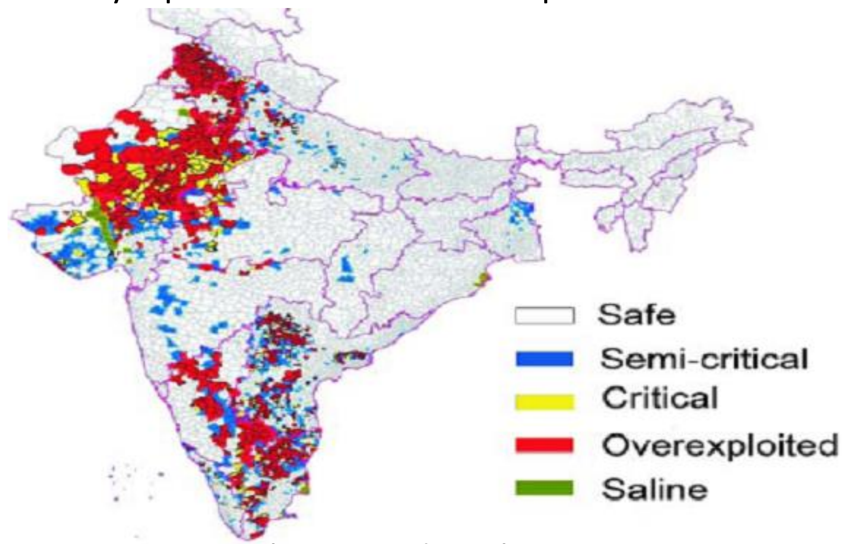
CHALLENGE: World Water Requirements



Source: 2030 Water Resources Group, 2013



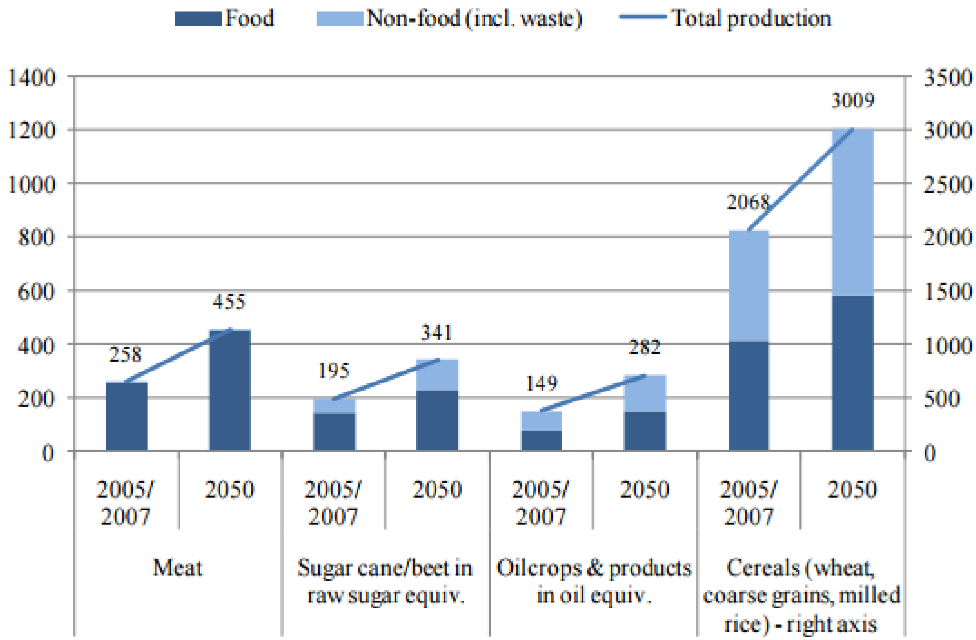
Many aquifers have been over exploited in India



Irrigation circles in Saudi Arabia

It is imperative that we improve water management efficiency

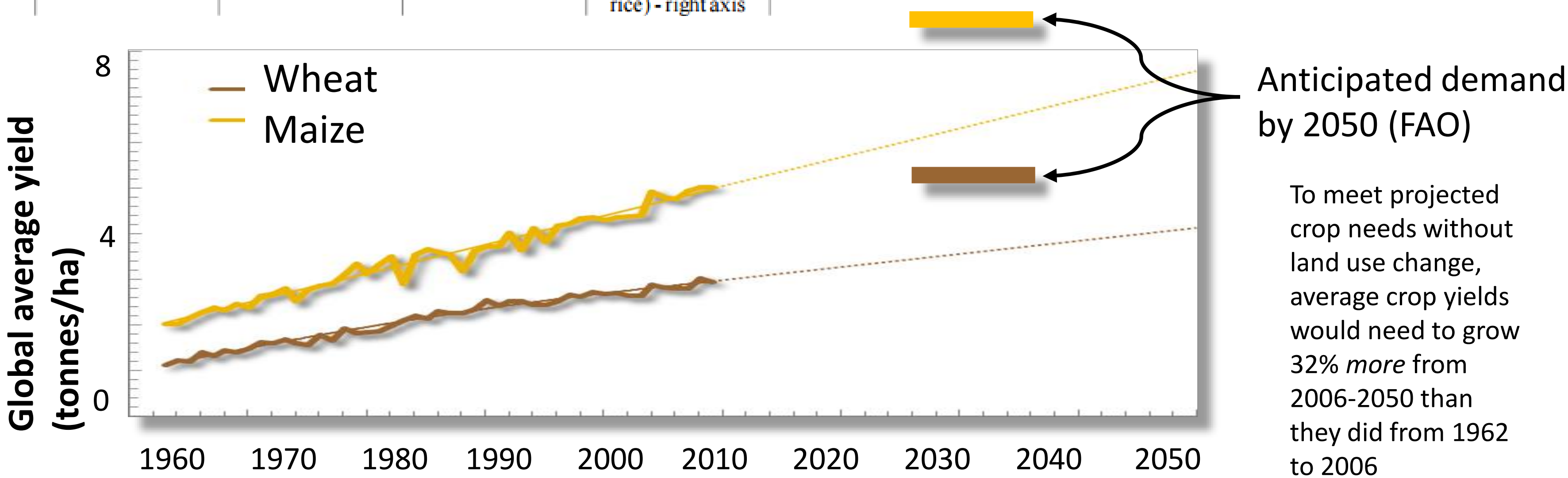
CHALLENGE: World Food Requirements



World agricultural production needs to rise by 60% by 2050 to meet demand

The world level increases in food demand are 70% determined by population growth and 30% by per capita income growth

Source: World Agriculture Towards 2030/2050: 2012 Revision, UN



Source: USDA PDS database

To meet projected crop needs without land use change, average crop yields would need to grow 32% *more* from 2006-2050 than they did from 1962 to 2006

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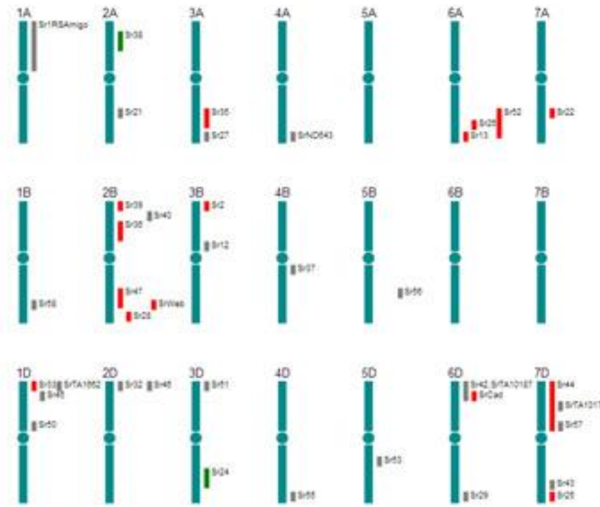
OPPORTUNITY: Biotechnology



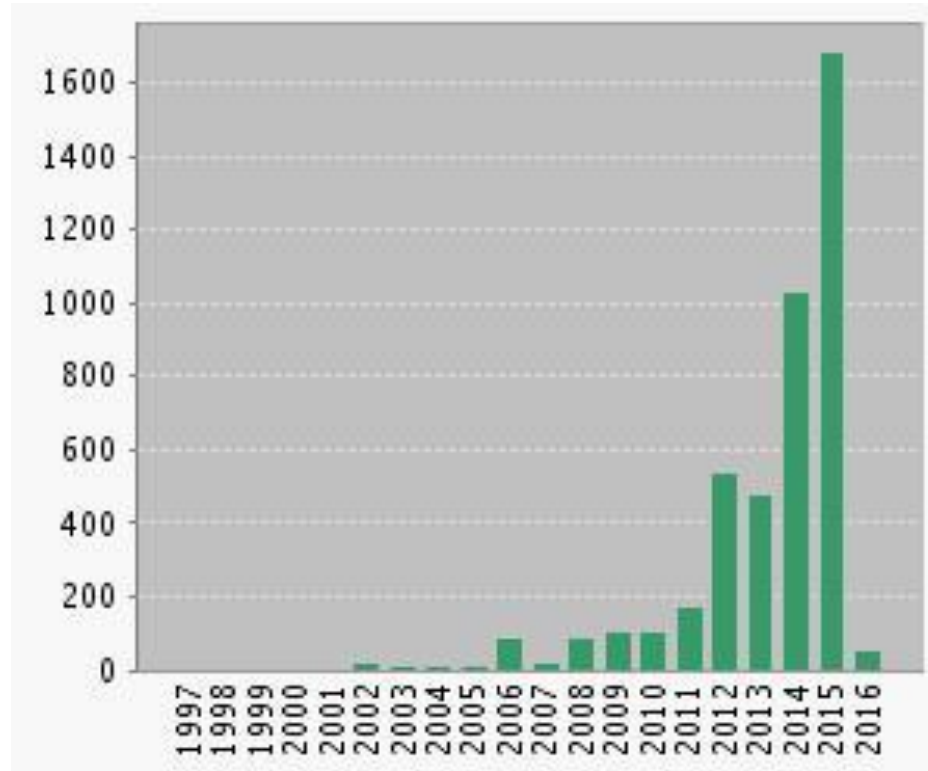
Molecular breeding: Wheat rust, the ‘polio of agriculture’, can destroy 50% of a farmer’s crop in one epidemic , and evolving resistance means 90% of all current African wheat varieties are currently susceptible. Marker assisted selection techniques allow researchers to map rust resistance genes (right) to assist in the breeding of resistant varieties

Genome data: in 2014 the 3000 Rice Genomes Project published 3000 rice strain genomes, quadrapling the current amount of publicly available rice genome data

Genetic manipulation: Rothamsted researchers have developed Camelina plants that accumulate Omega-3 long chain polyunsaturated fatty acids in their seeds; this would reduce the need for fish oil consumption by humans

Gene Editing:
the biggest biotech discovery of the century

- Allows scientists to rapidly and cheaply ‘search and replace’ for stretches of DNA, making targeted gene manipulation dramatically easier
- Applications range from disease resistance in plants to disease modification in humans



Published journal articles on gene editing (Source: Web of Science, Jan 2016)

OPPORTUNITY: Big Data

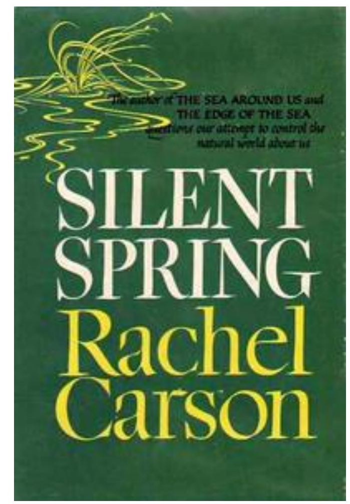
- Data availability
  - E.g., growth in high resolution satellite sensors opens up opportunities ranging from urban monitoring to ocean monitoring
  - E.g., household survey data has quadrupled since 2010
- Computing power
  - E.g., the Met Office new supercomputer, costing £97m (2014), will be one of the fastest in the world, performing more than 16,000 trillion calculations per second
  - the next-generation weather and climate models are expected to reach the exascale by 2020, being able to perform a million trillion calculations per second and providing weather forecasts with resolution to 300 metres

CHALLENGE: Political reactions to bad practice

Another unanticipated consequence

under-regulated use of chemicals

corporate and governmental bad practice and poor PR



inherent distrust & misunderstanding of modern agriculture

European Regulations on Pesticides

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- Regulations/Directives on pesticides in last 26 years has limited availability and made introduction of new products expensive
- Three types of neonicotinoid insecticides (first introduced in the 1990s and accounting as a class for 1/3rd of the global insecticide market) were banned in Dec 2013
- **Loss of pesticide capability through regulation or resistance could have a major impact, e.g. yield loss in the UK from the ban on neonicotinoids is predicted to range from 12% (in wheat and potatoes) to 50% (in onions) (Source: Andersons, 2014)**

European Regulations on GMO

- Only one GM crop has been approved in Europe since 1998, a Bt-insect-resistant maize
- It costs between $7n and $14m more to develop a GM crop for the European market than for the US market
- Crops genetically resistant to infectious disease are far preferable to other control methods; they do not damage non-target organisms, reduce human exposure to chemicals, and do not incur CO2 emissions via application

GM Safety

- UK Council for Science and Technology: over the 19 years that GM crops have been cultivated (they now make up 12% of global arable land) no risks from transgenes of any type have been identified
- Even in the highly litigious USA there have been no successful lawsuits, no product recalls, no substantiated ill effects, and no other evidence of risk from a GM crop product intended for human consumption
- European Academies Science Advisory Council: there is no rational basis for the current stringent regulatory process

Political attitudes to evidence-based policy

President Juncker: “The [European] Commission should be in a position to give the majority view of democratically elected governments at least the same weight as scientific advice [on the regulation of GMOs]”

Richard Lochhead, Rural Affairs Secretary for Scotland: “Scotland is known around the world for our beautiful natural environment – and banning growing genetically modified crops will protect and further enhance our clean, green status…I have heard directly from food and drink producers in other countries that are ditching GM because of a consumer backlash…I strongly support the continued application of the precautionary principle in relation to GM crops”

Political attitudes to evidence-based policy

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From a lobby group of NGOs to Juncker, July 2014: “We appeal to you to scrap this position [the post of Chief Scientific Advisor to the President of the EC]…the role is unaccountable, intransparent [sic] and controversial”

Prof Anne Glover from the University of Aberdeen was appointed as Chief Scientific Adviser in 2012

Researchers 'appalled' as EU chief scientist role is axed

BBC NEWS 14 November 2014

Professor Sir Paul Nurse, President of the Royal Society: "Scientific advice must be central to EU policy making, otherwise you run the risk of having important decisions being unduly influenced by those with mixed motives"

Political attitudes to evidence-based policy

President Obama: "Promoting science isn't just about providing resources – it is also about protecting free and open enquiry. It is about listening to what scientists tell us, even when it's inconvenient – especially when it's inconvenient."

Steven Chu, US Secretary of Energy: "People are entitled to their own opinions, but they are not entitled to their own facts"

OXFORD MARTIN COMMISSION FOR FUTURE GENERATIONS

Securing the long term in national and global decision making

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The Changing Global Balance

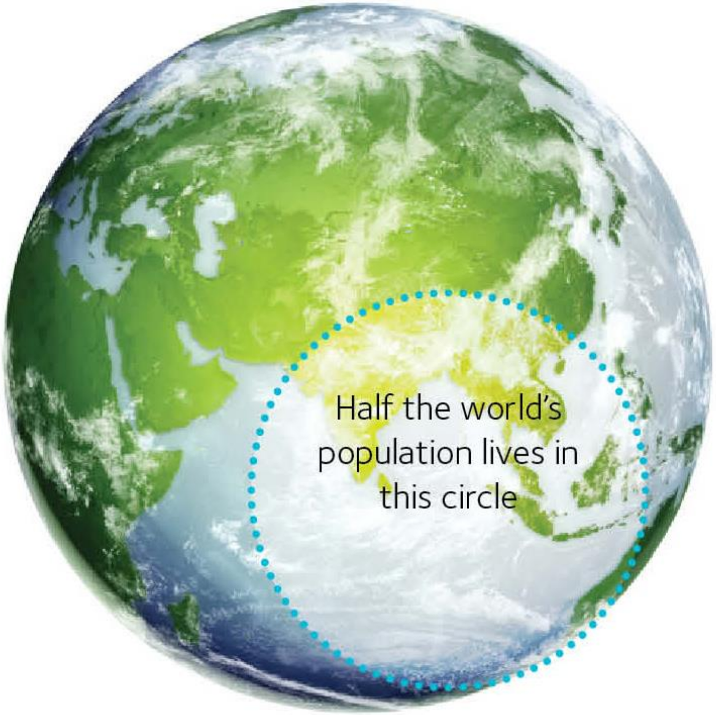


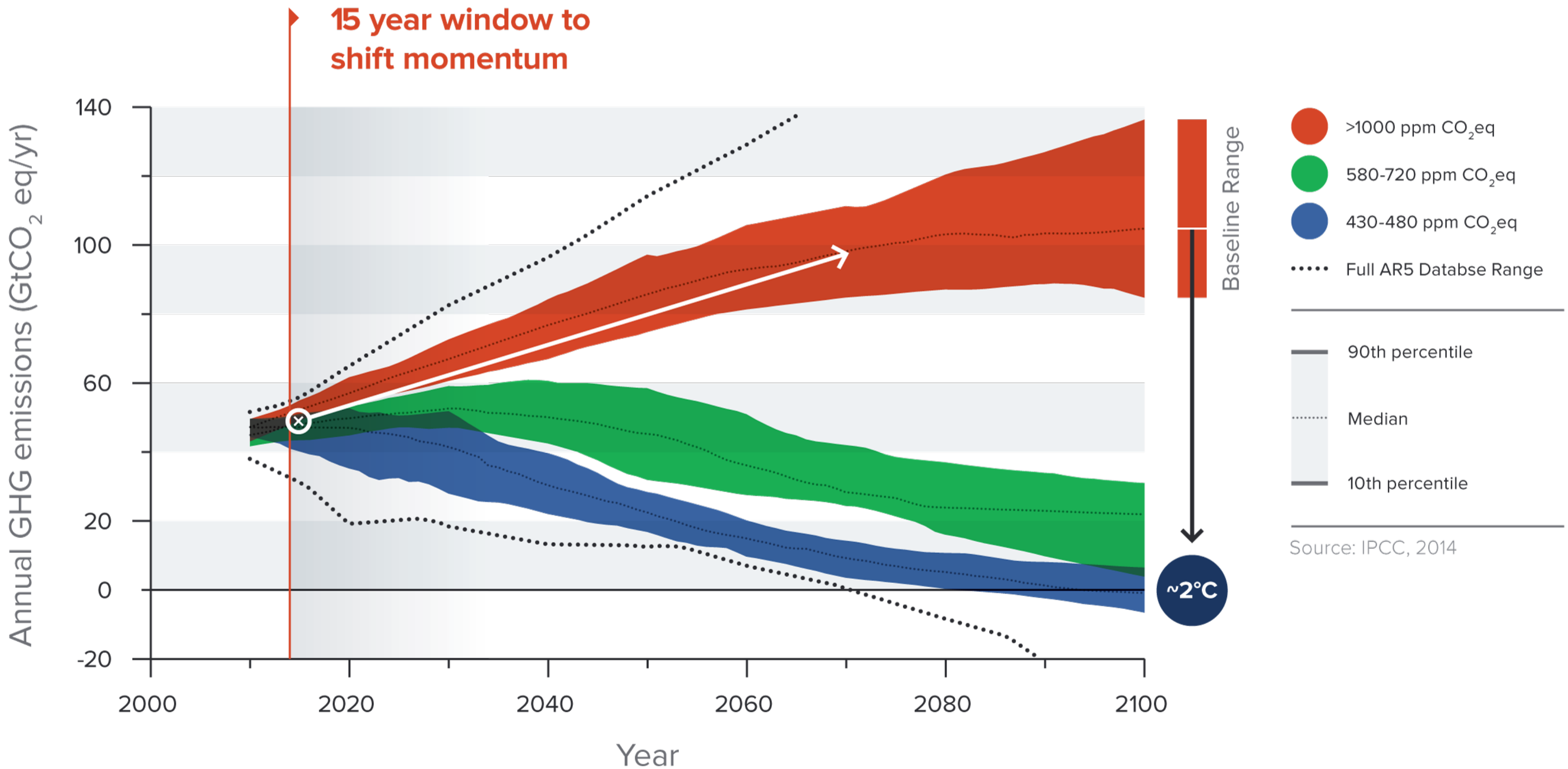
Figure 2: Global population distribution, 2013

Source: Oxford Martin Commission for Future Generations.

Africa in 2030: 1.6bn people, 800m of working age
Europe in 2030: 700m people, 460m of working age
Asia in 2030: 4.9bn people, 3.3bn of working age

But what about after 2030?

CHALLENGE: GHG emissions projections



- Climate performance is off track even versus a target of 450ppmm (c.2^{o}C warming)
- The next 15 years is critical

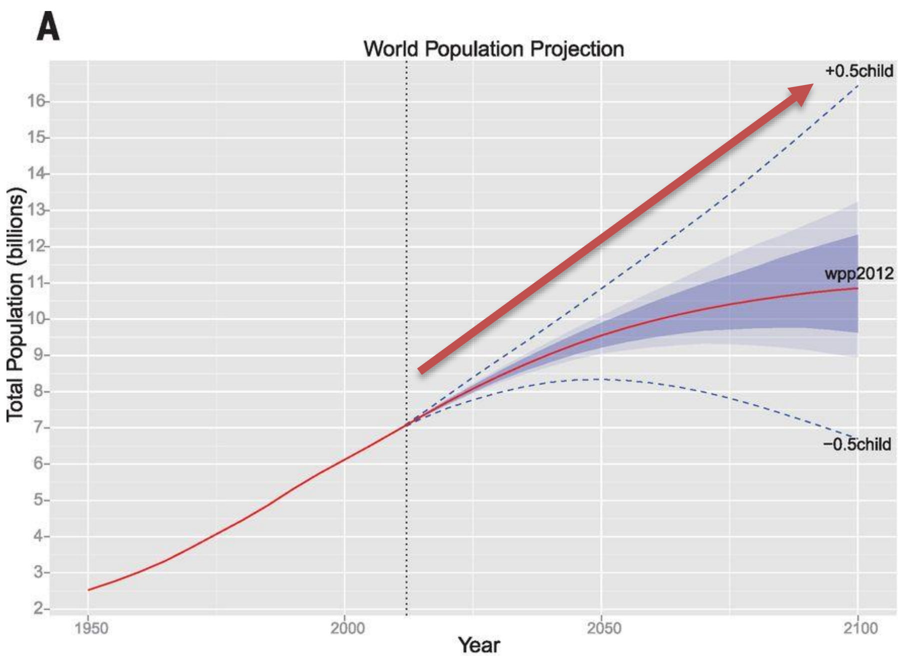
Risk of tipping points for global population

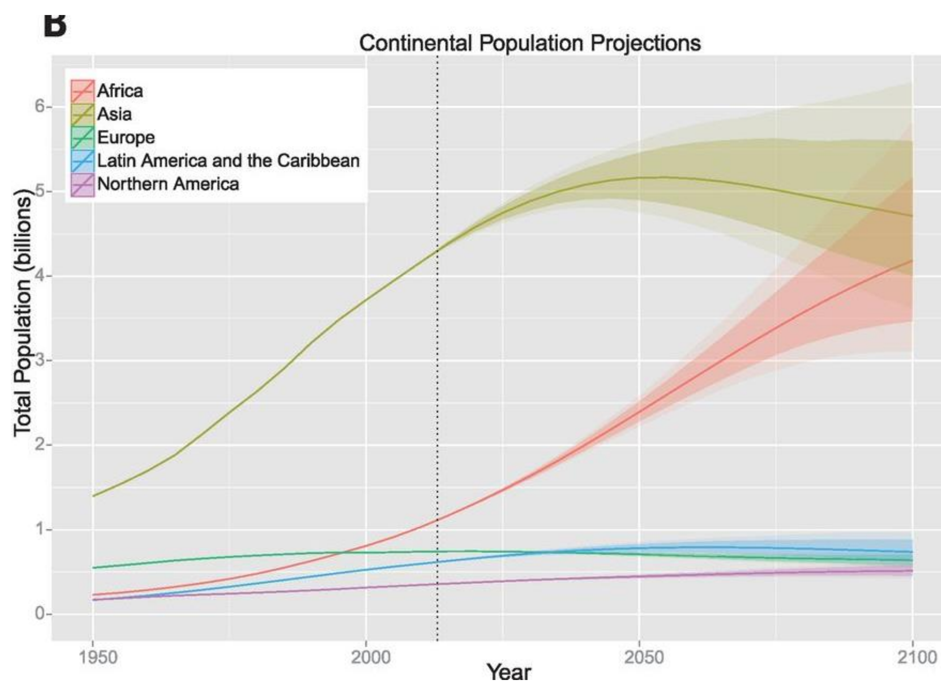
We are close to a tipping point for the long term growth of world population, depending on near term female fertility

theguardian

World population to hit 11bn in 2100 – with 70% chance of continuous rise

New study overturns 20 years of consensus on peak projection of 9bn and gradual decline





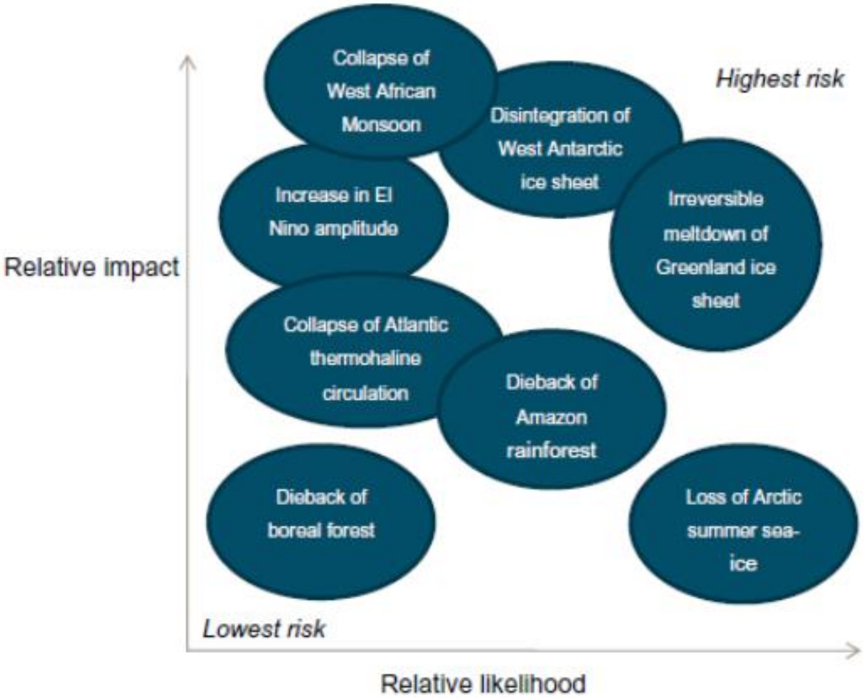
Left: UN high and low variants (dashed blue lines)

Right: UN 2012 world population projection (solid red line), with 80% PI (dark shaded area), 95% PI (light shaded area)

P Gerland et al. Science 2014;346:234-237

Challenges up to 2050

- Population – 2.4 billion more people
- Urbanisation – 66%
- A more prosperous world?
- Risk of tipping points in climate change
- Migration to vulnerable areas



Source: Prof Tim Lenton, Tipping Points UK Government Meeting 2011

	2050 (with no policy change)	Source
Food	+60%	FAO (TOWARDS 2030/2050)
Water	+55%	OECD Environmental Outlook to 2050
Energy	+80%	OECD Environmental Outlook to 2050
Emissions (GHG)	+52%	OECD Environmental Outlook to 2050