drivers of change

climate change & ocean health

Curated by Tim Jarvis

TIM JARVIS

THE SHACKLETON CLIMATE PROJECT

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population growth

how much water will 9bn people need?

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Historically, the rate of global water consumption has doubled every 20yrs — which is double the rate of population growth. If population and consumption trajectories continue, 1.8bn people will be living in water scarce regions by 2025. —Population Institute (July 2010)

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population growth

The global population reached 7bn in 2011 and is projected to reach 9bn by 2050. Growth is driven by increasing life expectancy and a rise in the number of women surviving to reproductive age, particularly in developing Africa and Asia. Sub-Saharan Africa — which accounted for 10% of the world's population in 2000 — will host 17% of the world's population by 2050. By 2050, the population of every country in East-, Southeast-, South- and Central Asia (excluding Japan and Kazakhstan) will grow substantially, with numbers nearly doubling in Pakistan, Nepal, Bangladesh, Afghanistan, Cambodia, and Laos.

As populations expand, demand for water will increase dramatically. This will be driven primarily by a growing demand for food — which is expected to increase by 70% by 2050 — and associated agricultural water use, expected to increase by at least 19% by 2050. A growth in overall consumption will lead to more water use in the manufacturing and production sectors. Consumer spending in India, for example, is expected to expand from US$991bn in 2010 to US$3.6tr by 2020.

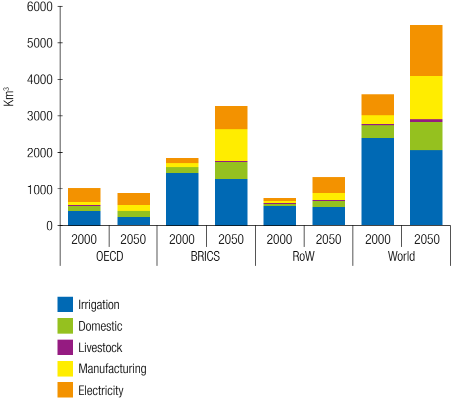

Fig 1: Global water demand: Baseline scenario 2000 and 2050
[OECD, 2012]

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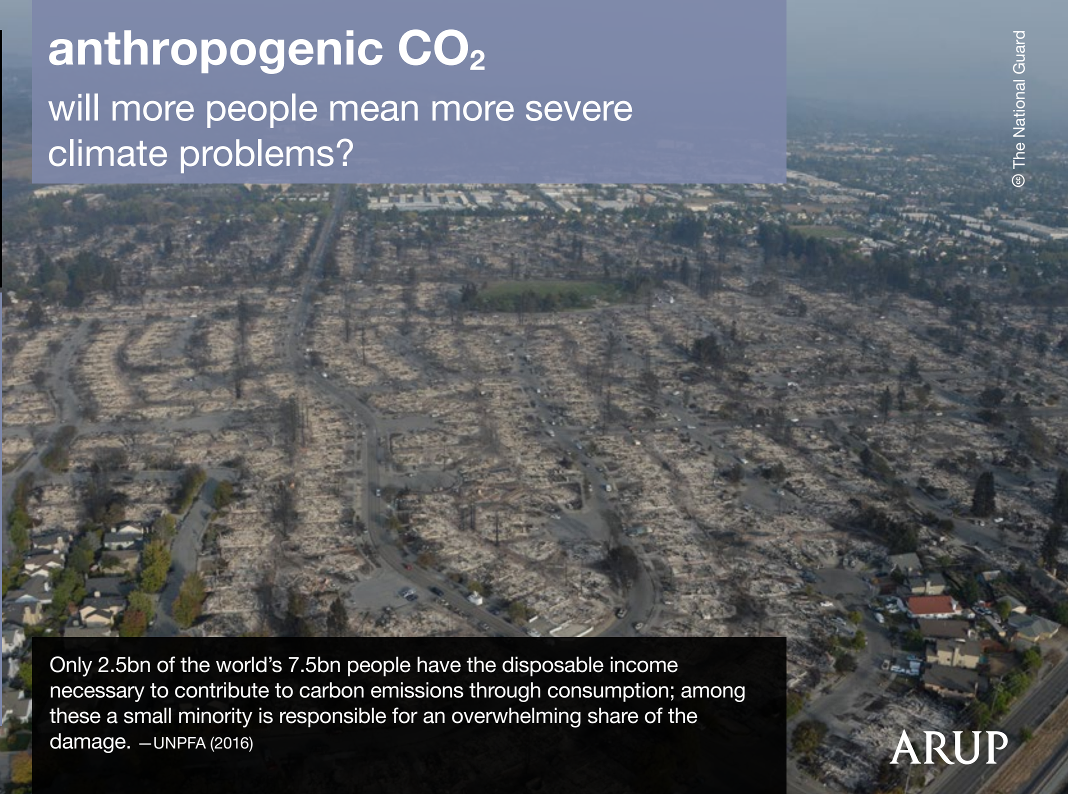
anthropogenic CO_2

will more people mean more severe climate problems?



Only 2.5bn of the world's 7.5bn people have the disposable income necessary to contribute to carbon emissions through consumption; among these a small minority is responsible for an overwhelming share of the damage. —UNPFA (2016)

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anthropogenic CO_2

Anthropogenic carbon dioxide emissions, steadily increasing over the past century, are widely understood as a principal driver of shifting global climate patterns. Economic and population growth are the key determinants of long-term CO_2 emissions (Fig 1); as population trends evolve, so will humanity's impact on the planet. A complex mix of factors such as changing life expectancies, migration flows, and employment rates may affect societies' contributions to climate change, but the general consensus is that as the population increases and becomes wealthier, climate change-related impacts on resources will accelerate.

Awareness of the impact of CO_2 emissions is increasingly widespread, and climate regulation is predicted to become more stringent as consequences of emissions become increasingly visible. At present, many nations with the highest emissions levels report the lowest levels of concern for the issue, decreasing the likelihood of short-term national political solutions (Fig 2).

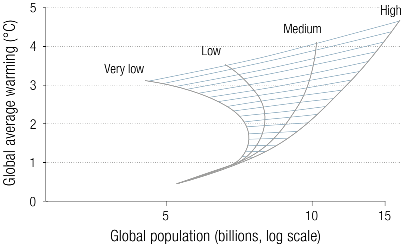


Fig 1: Effect of population growth scenarios on climate change
[CEPR 2014]

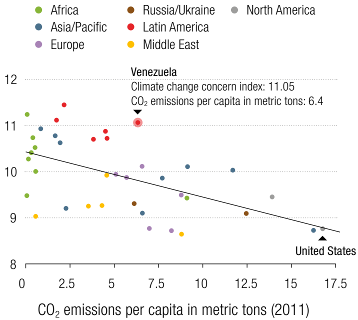
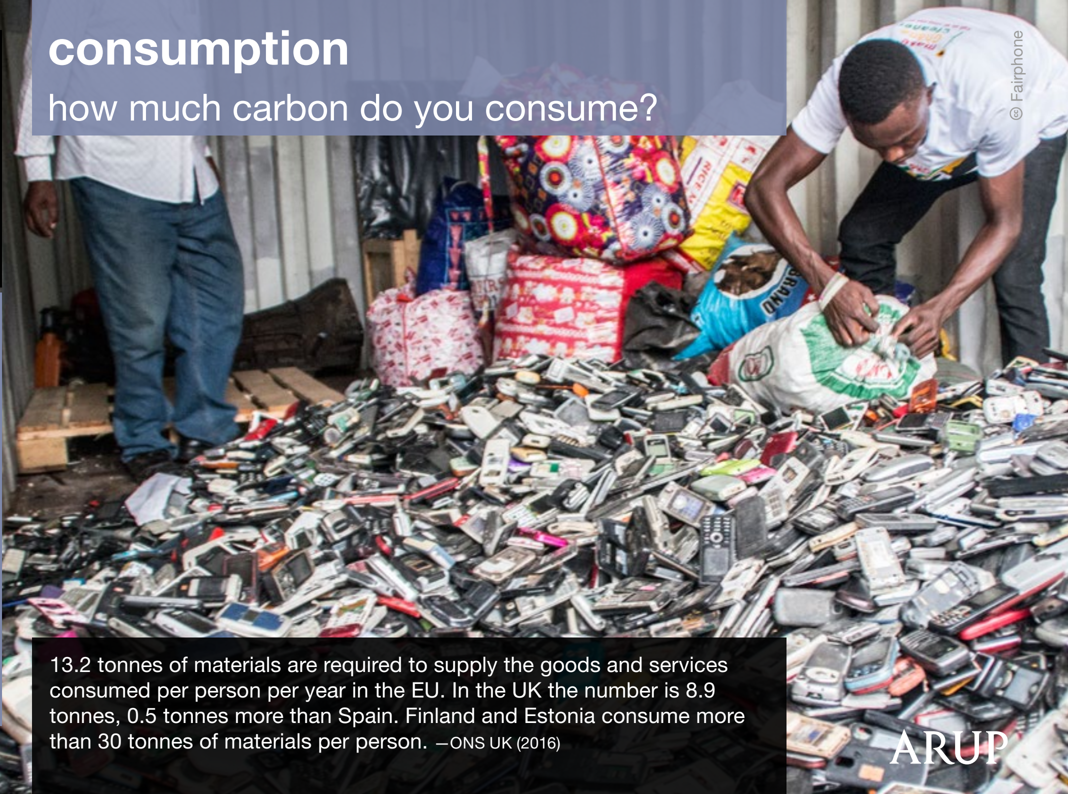


Fig 2: National climate change concern vs per capita CO_2 emissions
[Nature, 2017]

consumption

how much carbon do you consume?



13.2 tonnes of materials are required to supply the goods and services consumed per person per year in the EU. In the UK the number is 8.9 tonnes, 0.5 tonnes more than Spain. Finland and Estonia consume more than 30 tonnes of materials per person. —ONS UK (2016)

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consumption

Household consumption is responsible for more than 60% of global greenhouse gas emissions and 50–80% of all land, material and water use. 80% of these impacts result from supply chains, rather than individual behaviour such as driving or taking long showers. Average global carbon footprint per capita is 3.4 tonnes CO_2 equivalent, ranging from over 18 tonnes in the US to 1.8t in China, and even less in developing countries (Fig 1).

Historically, emissions have increased with economic growth, suggesting that emissions reductions will impede markets. However, 21 countries have demonstrated sustained decoupling of growth from emissions over a 14-year period. The UK cut CO_2 emissions by 24% between 2000 and 2014, while GDP grew by 27%. As a result, the nation's carbon intensity — CO_2 emissions per unit of GDP — dropped 40%.

Improving the useful life of manufactured products is one effective path to meeting increasing consumer demand while staying within emission targets. Lifecycle energy analysis — a calculation of the total emissions generated over an object's life from manufacturing to disposal — can encourage the development of products with longer useful lives, as well as more efficient production methods (Fig 2).

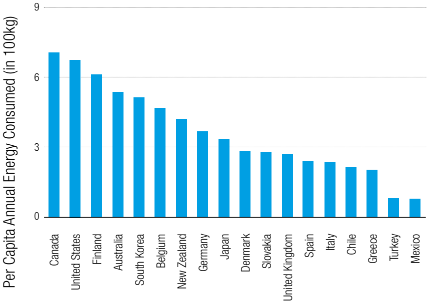

Fig 1: Municipal Waste Generation
[OECD, 2015]

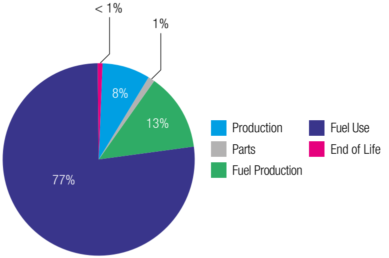

Fig 2: Life cycle GHG emissions analysis of passenger cars
[European Environment Agency, 2010]

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urbanisation

do you know your city's long-term plan?

Brazil is 'blessed' with 1/8 of the world's freshwater, but its natural disaster monitoring service estimates that Sao Paulo's main reservoir could run dry within the next year. The water utility has already lowered pressure in the system to reduce flow. —New York Times Online (16 February 2015)

urbanisation

The percentage of the global population living in urban areas is expected to reach 66% by 2050. A review of the world's developing regions reveals that Africa and Asia are the two regions suffering most from lack of urban water supply and sanitation. Major concerns include over-exploitation and pollution of water sources. According to The Times of India, 22 out of 32 major Indian cities deal with daily water shortages. This is driven by a steady increase in demand, inefficiencies in transfer and use, and persistent water pollution. Inadequate infrastructure — such as lack of wastewater treatment and drainage facilities — can lead to pollution of ground- and surface water supplies.

In addition to a shortage of reliable water supplies, the street surfaces of many cities continue to be highly impermeable to water. As a consequence, stormwater management has become a high priority to prevent floods and sewer overflows. Investment in green infrastructure — such as bioswales which use vegetation at street level and subterranean storage to soak up storm water — is leading to more sustainable forms of urban water management.

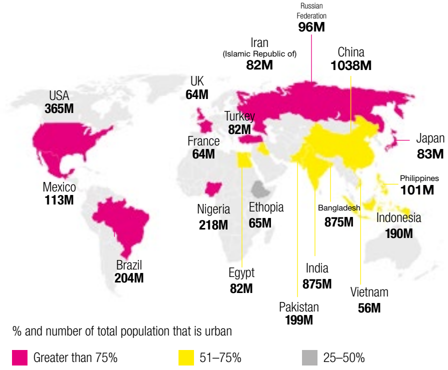


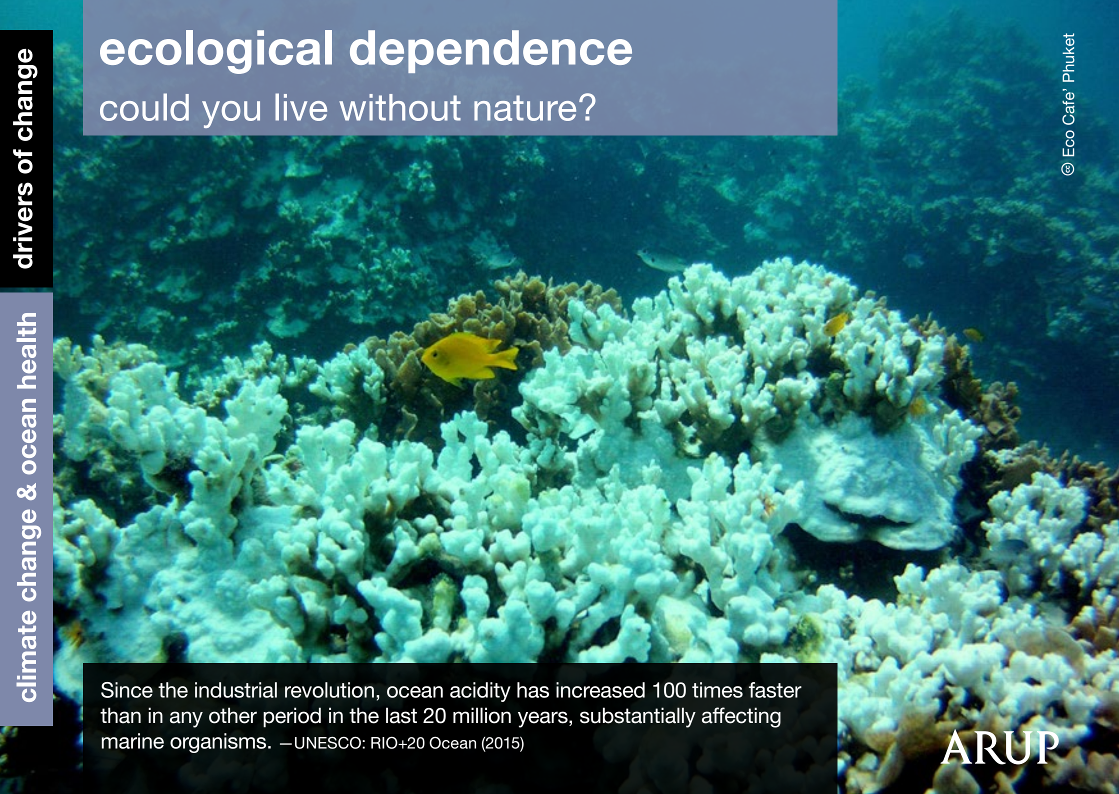
Fig 1: Urban population 2050
[UNICEF, 2012]

Urban Agglomeration	Country	Population
Tokyo	Japan	36,933,000
Delhi	India	21,935,000
Mexico City	Mexico	20,142,000
Shanghai	China	19,554,000

Fig 1.1: Largest cities under water stress
[Global Enviromental Change, 2014]

ecological dependence

could you live without nature?



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Since the industrial revolution, ocean acidity has increased 100 times faster than in any other period in the last 20 million years, substantially affecting marine organisms. —UNESCO: RIO+20 Ocean (2015)

ecological dependence

Anthropogenic CO_2 emissions have resulted in increased absorption of atmospheric CO_2 in the world's oceans. As a result, ocean acidity has risen 30%, with predictions indicating these levels may rise by 150% by the end of the 21st century. Research has shown that the changing chemical composition of the ocean is inhibiting marine organisms' ability to build reefs through shell calcification (Fig.1). Declines in reef stability and longevity affect marine food webs, species composition, and ultimately the entire ocean ecosystem.

Reef-building tropical and subtropical corals are among the species worst affected by the combined stresses of ocean warming, acidification, overfishing and pollution. In the last 30 years, the world's coral reef cover has diminished by 50%, with 75% of remaining reef systems threatened. Nearly 25% of aquatic species rely heavily on the 1% of ocean covered by coral reefs.

The state of our oceans is of worldwide concern, but particularly so in the developing world, where local populations rely heavily on the sea (Fig 2). Stocks of the most widely-used food fish — tuna, mackerel and bonito — have fallen by 74%, endangering global food security. Evidence shows that effective management can successfully rebuild fish stocks.

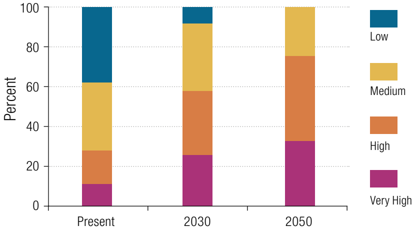

Fig 1: Present and projected global coral reefs at risk
[WRI, 2012]

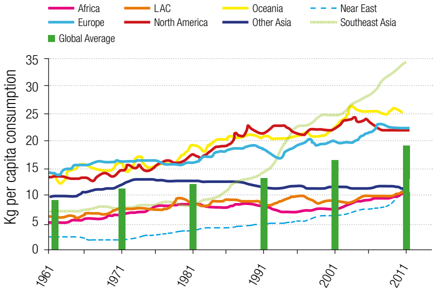

Fig 2: Regional evolutions of fish consumption per capita
[Commitee on World Food Security, 2014]

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tipping points

can we reverse endangerment?

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Estimates put the current loss rate of plant and animal species at between 1,000 to 10,000 times higher than Earth's natural extinction rate.
—World Wildlife Fund (2016)

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tipping points

When a climate system reaches its ‘tipping point’ (the threshold at which the future state of a system is irreversibly altered) drastic change becomes a permanent condition. Extra-systemic climate ‘forcing factors’ are often the initial drivers of climate change; these include declines in surface reflectivity (albedo), and human-induced aerosol emissions. As these forcing factors increase in frequency and severity, the process accelerates, leading to irreversible and catastrophic developments. Polar ice loss, ocean circulation shifts, rapid methane release, rainforest deforestation, weather instability and the mass extinction of marine and terrestrial species are potential tipping points, endangering earth’s ecosystem as a whole (Fig 1).

Biologists believe we may be entering a sixth mass extinction — the first such extinction caused by a species (humans). Data indicates that one in six extant species may vanish as a result of anthropogenic climate change over the next century. Since 1500AD, more than 750 species have become extinct; as of 2014, another 5,552 are threatened (Fig 2). The World Wildlife Fund estimates that over 50% of Emperor and Adélie penguins will disappear by 2050 if global temperatures continue to increase above pre-industrial levels (2°C).

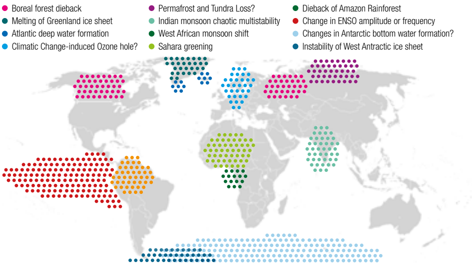


Fig 1: Potential tipping elements in the earth system
[C2ES, 2014]

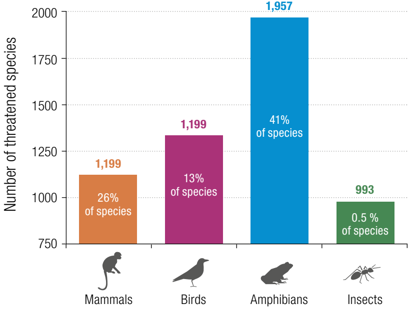
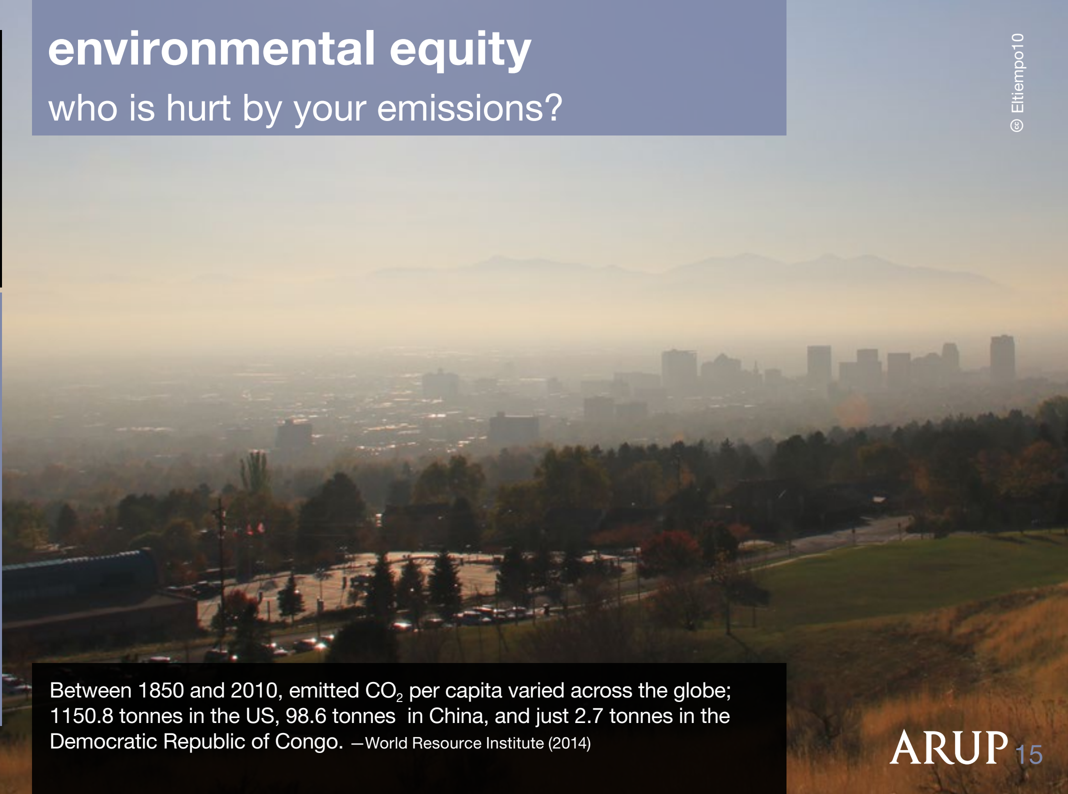


Fig 2: Existing species threat of extinction
[Nature, 2014]

environmental equity

who is hurt by your emissions?



Between 1850 and 2010, emitted CO_2 per capita varied across the globe; 1150.8 tonnes in the US, 98.6 tonnes in China, and just 2.7 tonnes in the Democratic Republic of Congo. —World Resource Institute (2014)

environmental equity

Environmental equity is the development, implementation and enforcement of environmental policies ensuring that nations with little economic or political clout are not made to bear a disproportionate share of harmful pollution effects. Wealthier countries are often leading carbon emitters, while poorer nations and lower income demographics generally emit significantly less carbon yet suffer the most from climate change impacts. One step toward more universal equity is a process of the UN Framework Convention on Climate Change, allowing nations to propose climate action plans tailored to local economic and demographic trends, while aligning with collective guidelines.

In 2013, the top three emitting regions accounted for over half of global CO_2 emissions, with China responsible for 29% (10.3bn tonnes), the US 15% (5.3bn), and the WU and the EU 11% (3.7bn) (Fig 1). In 2014, China's per capital emission levels exceeded mean EU levels for the first time in history (Fig 2). Projected effects of high emissions include decreased agricultural yields, harm to human health and lower worker productivity. The 2014 economic damage of these emissions, known as the *social cost of carbon*, was estimated between US$37 and US$200 per tonne.

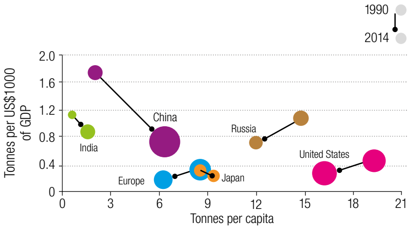


Fig 1: Energy-related CO_2 emissions per capita by region
[International Energy Agency, 2015]

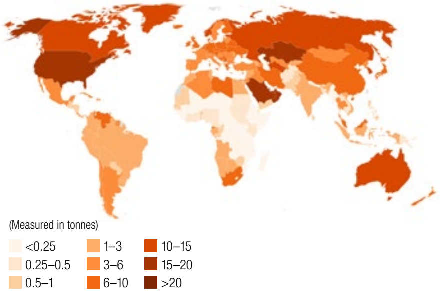


Fig 2: Comparing climate equity, CO_2 per person
[Carbon Map, 2016]

the big thaw

how high could the seas rise?

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Global CO_2 concentrations have not exceeded 300 parts per million (ppm) in the last 800k years. Today, concentrations are 407ppm (2016) and could reach as high as 935 ppm by 2100 at current emissions rates. Present levels are already sufficient to gravely accelerate the melting of all ice in Greenland.
—U.S. Global Change Research Program (2014)

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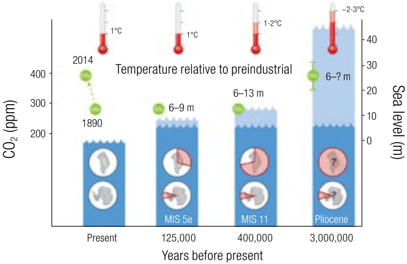
the big thaw

One of the most tangible impacts of global warming is the widespread disappearance of land and sea ice. Global sea warming, and expanding waters, account for one-third of universal sea-level rise, while the remaining two-thirds is a result of melting ice sheets in Greenland, Antarctica and mountain glaciers. Extreme projections of polar ice sheet melting anticipate a resultant rise in sea levels of over 6 metres by the end of this century (Fig 1).

Satellite observation of Arctic sea ice has shown that the ice is diminishing at a rate of 13.4% per decade relative to the 1981 to 2010 average; 2015 holds the record for the lowest summer ice coverage since 1979 (Fig 2). This trend also occurs on land; the US Geological Society found that glaciers within Wyoming's Glacier National Park have declined from an estimated 150 in 1850 to just 25 in 2010.

Ice cover reduction contributes to sea level rise and loss of both water habitats and freshwater supply. Cascading effects include reduced reflection of solar radiation, increased global heat absorption, increased methane and carbon dioxide release from melting permafrost, and changes to oceanic circulation and global weather patterns.



Peak global mean temperature, atmospheric CO_2, maximum global mean sea level (GMSL), and source(s) of meltwater.Light blue shading indicates uncertainty of GMSL maximum. Red pie charts over Greenland and Antarctica denote fraction (not location) of ice retreat.

Fig 1: Sea level rise projections based on historical ice loss and CO_2 data

[Science Magazine, 2015]

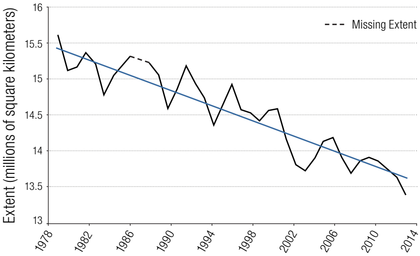


Fig 2: Arctic sea ice loss 1979–2013

[U.S. Global Change Research Program, 2013]

vanishing places

where will you live?

By 2050, between 50m and 350m people are likely to relocate due to climatic changes, sea level rise, increased water scarcity or desertification.
—Regional Academy on the United Nations (2012)

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vanishing places

Sea levels are currently rising faster than at any time in the last 22 years (Fig 1). Scientists predict an additional rise of between 0.9–1.2m by 2100. With nearly half of the world's population located within 150km of a coastline, global sea level rise and coastal erosion will dramatically impact where people can live. Port cities such as Alexandria, Barranquilla and New York are already imperiled by rising sea levels; in the near future, near-coastal cities where flood risk has not been a historical concern will also feel these impacts.

Areas further inland are also vulnerable; 12m hectares of land are lost to desertification and drought annually. Under IPCC's high emissions scenario, dryland biomes are projected to increase by 24% by 2100, to cover 56% of the planet's total land area (Fig 2). Persistent anthropogenic degradation of drylands, caused by deforestation, overgrazing and unsustainable agriculture, will intensify the effects of climate change. Today, over 38% of the global population lives in a dryland biome. As a result of desertification, 50 million people may be displaced within the next 10 years, a figure estimated to reach 135m people by 2045.

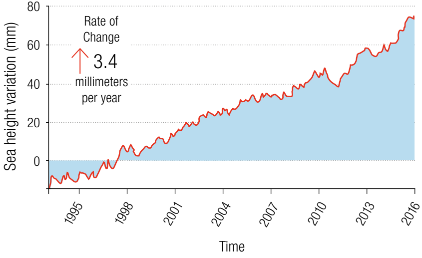


Fig 1: Sea level rise — rate of change per year
[NASA, 2016]

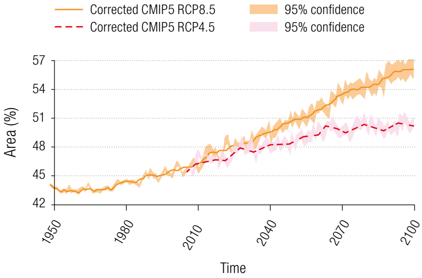


Fig 2: Percent global cover of dryland biome under RCP 8.5 and 4.5 projections
[Nature, 2015]

natural disasters

is your city prepared?

Of 1,692 global cities, only 93 are immune to any risk of hurricane, earthquake, flood, landslide or volcanic eruption. The only megacity in this group is Moscow, Russia. —UN (2015)

natural disasters

Natural disasters, major adverse events involving natural processes such as floods, hurricanes and earthquakes are increasing in both frequency and intensity. In the 600 largest cities in the world, the number of people at risk has exponentially increased over the past half-century (Fig 1). 379m city dwellers live at risk of flooding, 283m live in earthquake zones and 157m are at risk from windstorms. Coastal cities, home to 13% of the world's urban population, are seeing sea levels rise by over 3mm annually. Effects of natural disasters can be exacerbated by the high density and interdependence of city infrastructure, making challenging terrain for emergency responders.

Natural disasters can have significant economic effects beyond initial damage; the US city of New Orleans, heavily damaged by Hurricane Katrina in 2005, saw elevated levels of poverty persisting nearly a decade after the storm (Fig 2). Every US$1 spent on building urban disaster preparedness and resilience can save as much as US$4 in relief, recovery and reconstruction.

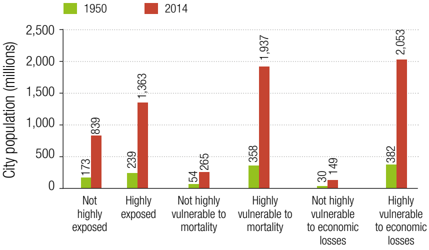


Fig 1: Urban residents at risk of natural disaster
[United Nations, 2015]

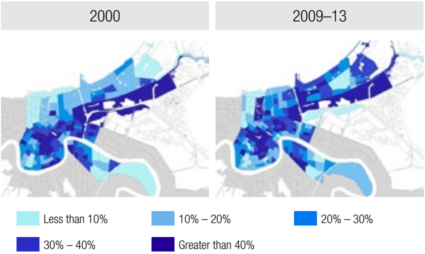
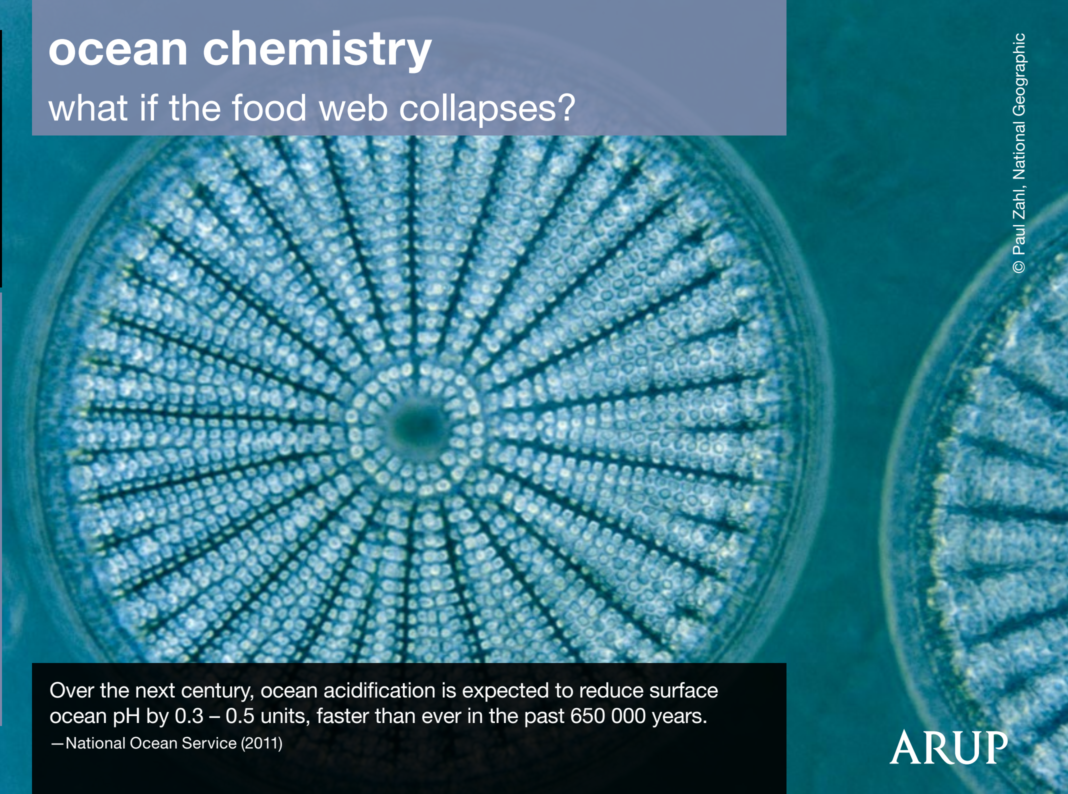


Fig 2: Neighbourhood poverty in New Orleans, pre- and post-Katrina
[The Brookings Institution, 2017]

ocean chemistry

what if the food web collapses?



Over the next century, ocean acidification is expected to reduce surface ocean pH by 0.3 – 0.5 units, faster than ever in the past 650 000 years.
—National Ocean Service (2011)

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ocean chemistry

The exchange of gases between the atmosphere and ocean is essential for life on Earth. Currently, between 30-50% of human generated CO_2 is taken up by the oceans. This has delayed the increase in atmospheric greenhouse gas concentrations that would otherwise have occurred and thereby has slowed the rate of global warming. Although beneficial in this respect, the absorption of additional CO_2 by the ocean has the negative consequence of making sea water more acidic. Since the beginning of the Industrial Revolution, the ocean pH* has decreased by 0.1pH units.

The marine food web depends on the pH content of seawater. A decrease in ocean pH affects the ability of marine organisms to fix dissolved calcium carbonate in sea water to create their exoskeletons. In the past it is thought that major climate change events have been accompanied by a large scale die-back of ocean life due to the absorption of carbon dioxide and methane acidifying the ocean. An example is the Paleocene-Eocene thermal maximum around 55M years ago. These events have had a major impact on life on Earth as the ocean plays a vital role in keeping oxygen levels in the atmosphere sufficiently high for high life to flourish. For example, prochlorococcus, a blue-green bacteria present in ocean water, generates approximately 20% of the oxygen in the atmosphere.

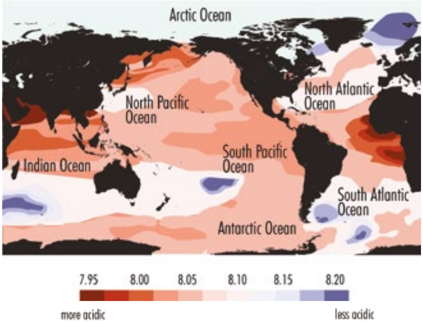

Fig 1: Variations in ocean pH
[[BBC, 2009]

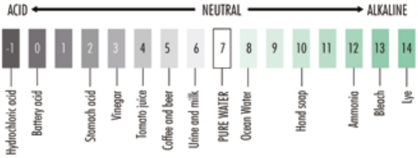

Fig 2: The pH acid/base scale
[NASA, 2011]

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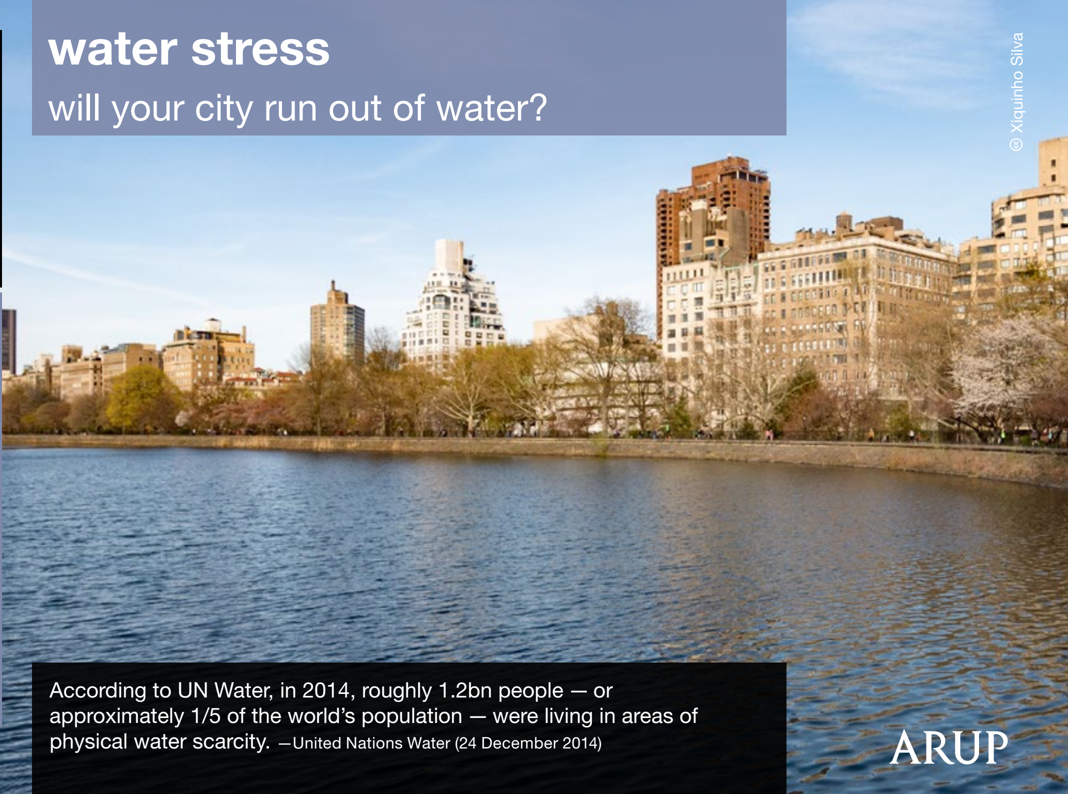
water stress

will your city run out of water?



According to UN Water, in 2014, roughly 1.2bn people — or approximately 1/5 of the world's population — were living in areas of physical water scarcity. —United Nations Water (24 December 2014)

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water stress

According to the European Environment Agency, “water stress occurs when the demand for water exceeds the available amount during a certain period.” At a national level, this is often measured using Falkenmark’s Water Stress Index (WSI), which divides the volume of available water for each country by its population. A country is considered to be “water stressed” if the average amount of water available per inhabitant is less than 1,700m^3, “water scarce” if that amount is less than 1,000m^3 and “absolutely scarce” below 500m^3. Bank of America Global Research predicts that 50% of the world’s population will be living in “water stressed” conditions by 2030.

Water stress and competing interests for limited resources often lead to political turmoil at regional, national or even international levels. Ethiopia’s Renaissance Dam project, for example, has angered Egyptian authorities, who claim it will limit their water supply, with some asserting a 25% reduction in farmland. Additionally, land grabs in water-secure nations seem to be on the rise, as at-risk countries aim to secure their food supply.

Ratio of withdrawals to supply

- > 80%
- 40–80%
- 20–40%
- 10–20%
- < 10%

Fig 1: Water stress by country
[World Research Institute, 2013]

health threats

will the climate make you ill?

The World Health Organisation estimates that diseases associated with anthropogenic warming and precipitation trends of the past three decades already claim more than 150,000 lives each year. —WHO (2014)

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health threats

Warming global temperatures contribute to both direct impacts on human health and economic consequences from a rising number of vector-borne diseases, including dengue fever, Lyme disease, malaria, and Zika virus. The geographic range of disease-carrying insects is expanding due to rising temperatures; in addition, climate change-driven rainfall, flooding and humidity patterns result in expanded breeding environments for these insect vectors.

In 2015, approximately 3.2bn people — nearly half the world's population — were at risk of malaria. Recently, University of Michigan ecologists determined that temperature directly affects the spread of malaria; average numbers of reported cases increase in warmer years and decrease in cooler ones. This relationship results in millions of additional infections per year for every 1°C rise in global temperature. Similarly, people living in large parts of Europe and the mountainous regions of South America — too cold today to support mosquito populations year-round — will within decades face outbreaks of dengue fever, for which no vaccine or treatment is available (Fig 1).

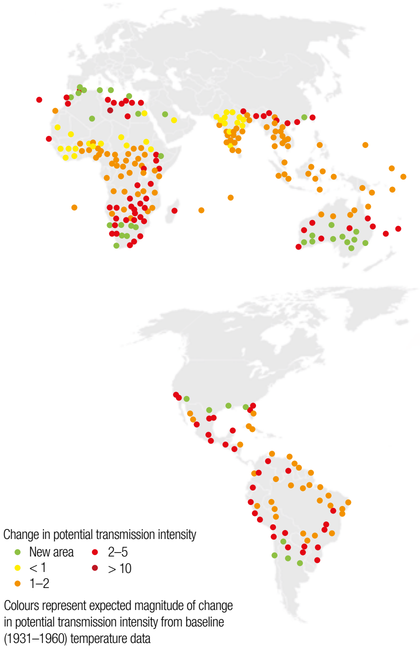

Fig 1: Projected dengue distribution for 2050 (2°C warming scenario)
[Nature Reviews Microbiology, 2015]

accumulated risk

can we insure against the ripple effect?

Average global economic losses from weather-related events jumped from US$50bn annually in the 1980s to nearly US$200bn in the last decade. Estimates suggest losses from investment assets as a result of climate change will reach US$143tr by 2100. —IPCC (2012), The Economist (2015)

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accumulated risk

Accumulated risk occurs when a disaster triggers a series of compounding consequences, resulting in amplified impacts. One example of this 'ripple effect' is the 2011 Tohoku earthquake, tsunami and nuclear incident in Japan. Effects of the 9.0-magnitude earthquake included nearly 16,000 deaths, 2,590 missing persons, US$220bn in damages, and a significant tourism decline nationwide. Follow-on losses cost US$55m in California, US$30m in Hawaii, and US $6m in Chile, crossing economic, cultural and geographic divides.

Many people, businesses and countries rely on insurance to protect against the economic hazards of extreme weather. Insurance industry research has found that the frequency and severity of extreme weather events has increased in recent years, leading to an increase in claims (Fig 1). In 2014, the world experienced 336 disaster events, up from 150 in 2003.

The insurance industry is keenly aware of the changing nature of climate risks and the associated increase in climate-related financial losses (Fig 2). Some insurers are raising premiums and cancelling policies in high-risk areas, while others are choosing to promote climate risk reduction and resilience strategies, including green infrastructure and catastrophe modelling.

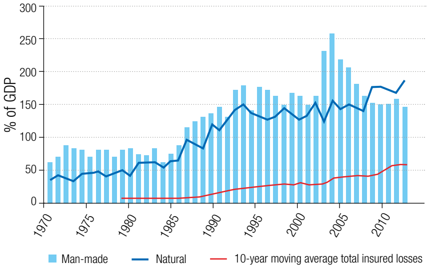


Fig 1: Catastrophic events over time
[Swiss Re, 2015]

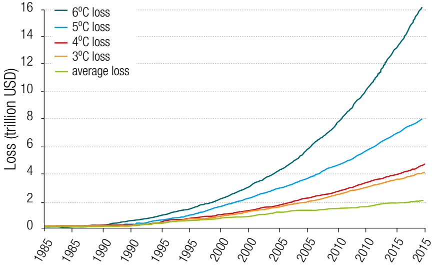
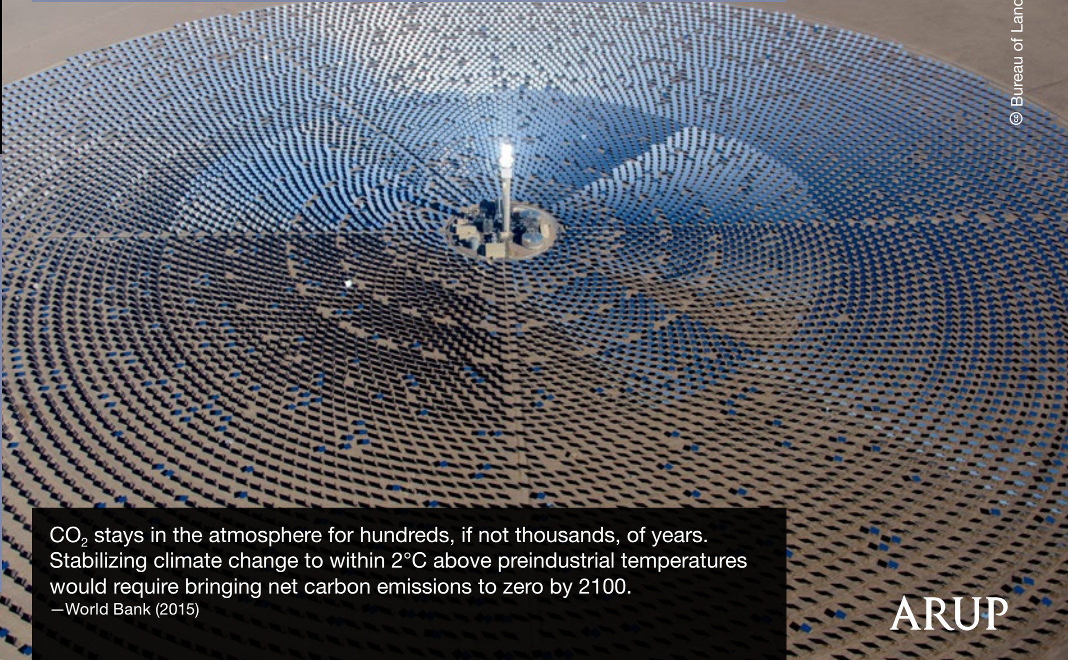


Fig 2: Projected global financial loss due to climate change
[The Economist, 2015]

decarbonisation

when will we be carbon neutral?



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CO_2 stays in the atmosphere for hundreds, if not thousands, of years. Stabilizing climate change to within 2°C above preindustrial temperatures would require bringing net carbon emissions to zero by 2100.
—World Bank (2015)

decarbonisation

Decarbonisation is the process of decoupling economic growth and energy supply from greenhouse gas emissions. The first step in this process is improving efficiency and conservation measures. For buildings or vehicles, the second step is often to switch fossil fuel use to electricity use (e.g. replacing a gas water heater with an electric heat pump water heater). Transitioning to electricity alone, however, does not reduce emissions unless that electricity is carbon free.

The third step is electricity sector decarbonisation, which involves replacing fossil fuel-based emissions sources (such as coal-fired power plants) with carbon-free sources. This shift away from fossil fuels to carbon-free electricity will lead to a doubling of the share of electricity in final energy consumption to more than 40% by 2050. Fuel switching is one of eight strategies required for ‘stabilization wedges’, a framework for minimising carbon emissions with currently available technology (Fig 1 & 2). When the stabilisation triangle was first introduced in 2004, seven wedges were needed; lack of emission reductions since 2004 has necessitated the identification of two additional wedges.

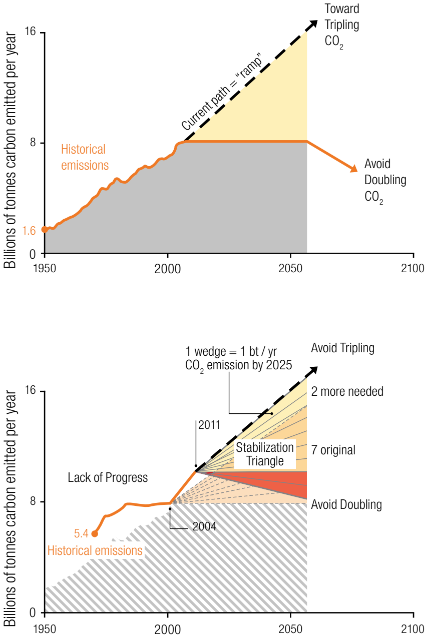

Fig 1 & 2: Carbon stabilisation wedges in 2004 and 2011, Pacala & Socolow

[Princeton, 2015]

drivers of change

climate change & ocean health

carbon pricing

should the polluter pay?

© Foto-Rabe

A revenue-neutral carbon tax in the US, where income is used to subsidise energy costs to consumers, could increase GDP by US$1.3tr by 2035. —REMI + Synapse (2014)

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carbon pricing

Carbon taxes can artificially raise the cost of fossil fuels responsible for CO_2 emissions. This tax approach leaves details of how and when to switch from fossil fuels to low-carbon alternatives to the market. Companies can avoid tax liability by investing in energy efficiency and low-carbon energy. Government tax income would be revenue neutral when used to reduce higher energy prices on lower income households, soften the impact on coal workers, or simply reduce other taxes. However, the tax might impact economic growth, and also there is no control on the amount of carbon emitted.

An alternative is a cap-and-trade market. Total emissions are capped, with emitters free to buy and sell emission permits in a market. Many countries have implemented one or both schemes (Fig 1).

Difficulties exist, however. The price can vary (Fig 2), causing investment uncertainty. If a cap is set too high, the market price will be too low for any influence. Trading nations need similar schemes to avoid competitiveness issues. Negotiations can be slow. Political support can also wane, like in 2014 when Australia repealed its carbon tax.

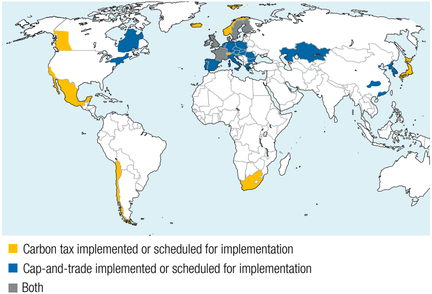

Fig 1: Implementation of carbon tax and cap-and-trade schemes (2015)
[WRI, 2015]

Fig 2: Price of carbon in the EU Emissions Trading System
[www.man.com, 2015]

subsidies

would you say "no" to cheaper bills?

Fossil fuel companies benefitted from an estimated US$5.3tr in global subsidies in 2015, more than the health spending of all the world's governments combined. —The Guardian (2015) and IMF (2015)

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subsidies

An energy subsidy is any measure that reduces energy costs for consumers or producers (Fig 1). Countries don't always agree what constitutes a subsidy, and they can remain 'hidden' in tax rebates, exemptions and concessions. Subsidies often help introduce new technology and infrastructure (e.g. renewables and cleaner fuels) and help them compete against incumbents by levelising the cost of generation. The OECD is calling for subsidy transparency to ensure fairness and clear exit strategies to avoid introducing market instability and uncertainty.

For mature fossil fuel industries, subsidies can distort inter-fuel competition, for instance making renewables less able to compete. The cost of energy to an economy is not reduced by subsidies, but redistributed via taxes or austerity in other areas. Thus subsidies do not always benefit the poorest, for instance. Subsidies can also create a cycle of under investment or a culture of reckless consumption. Subsidised fuel can reduce the perceived savings from energy efficient devices or buildings.

Subsidy change is closely linked to sensitive political issues (e.g. trade competition, poverty alleviation and the sovereignty of governments over natural resources), making them difficult to remove.

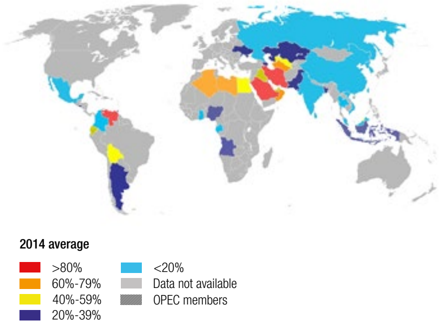
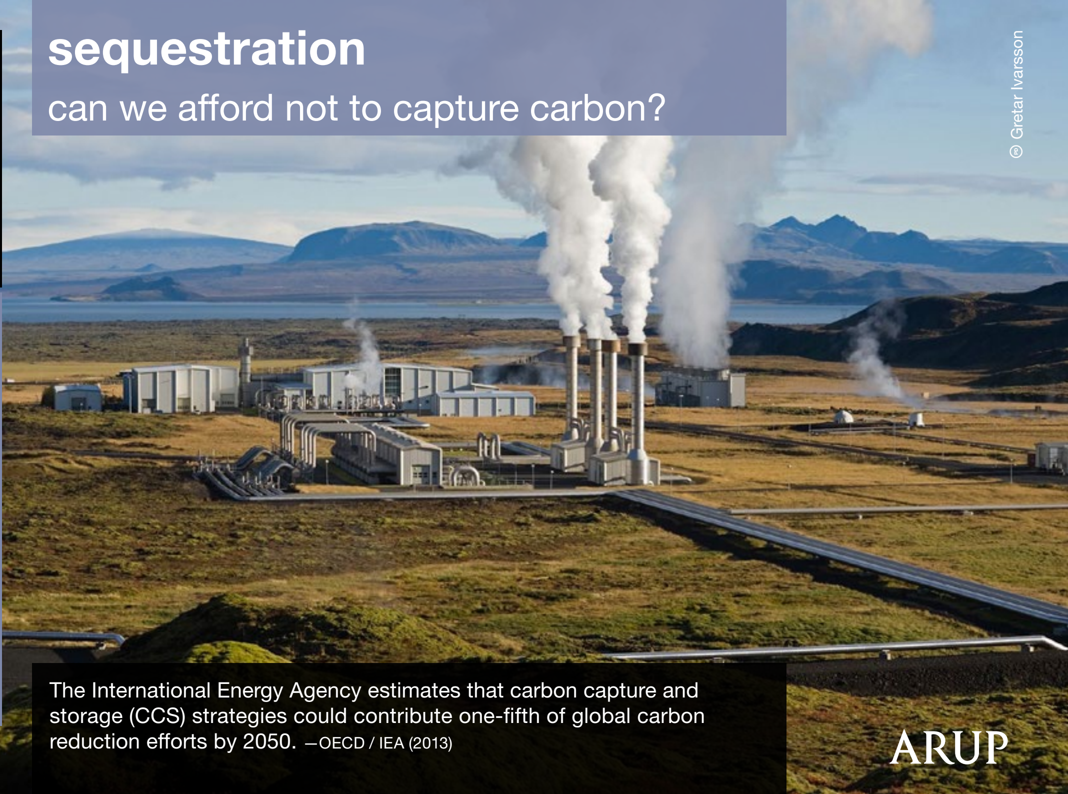


Fig 1: Fossil fuel subsidies as a proportion of full cost of supply in 2014 (for consumers and producers) [Thomson Reuters, 2012 and IEA, 2015]

sequestration

can we afford not to capture carbon?



The International Energy Agency estimates that carbon capture and storage (CCS) strategies could contribute one-fifth of global carbon reduction efforts by 2050. —OECD / IEA (2013)

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sequestration

Carbon sequestration may provide a path to stabilising atmospheric CO_2 levels while continuing to use fossil fuels, by recapturing and storing emitted carbon before it can enter the atmosphere. Nations around the world have set ambitious carbon-capture goals; OECD nations aim to capture between 3–5 billion metric tonnes of CO_2 by 2030, increasing to an average 15bn metric tonnes by 2050, while China hopes to capture 40bn metric tonnes of carbon in the same timeframe (Fig 1).

Proposed methods of sequestration include soil carbon enrichment and carbon capture and storage (CCS). Soil enrichment using charcoal-enriched ‘synthetic terra preta’ soils can contain 2.5 times the carbon of natural soil and may help mediate the worldwide decline in soil fertility.

CCS is a longer-term strategy to store carbon emitted by fossil fuel driven power stations. In this process, CO_2 is removed from a power station’s exhaust stream, liquefied, and injected into the porous rock strata of an aquifer or disused oil field (Fig 2). It is estimated that the deep aquifers of the world’s sedimentary basins alone have a potential total storage capacity of between 1,000 and 10,000 gigatons of carbon — between 100 and 1,000 years of CO_2 emissions at present day rates.

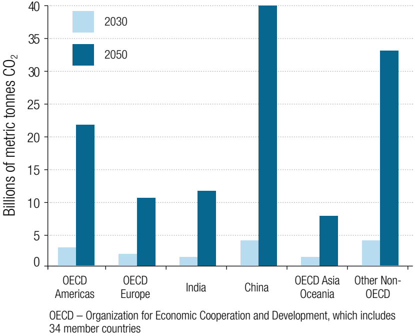

Fig 1: Long-term carbon capture goals
[MIT Technology Review, 2012]

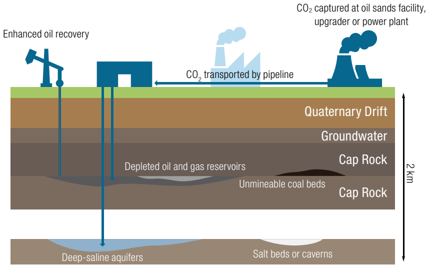

Fig 2: Geologic sequestration of CO_2
[CO_2 Solutions, 2014]

climate mitigation

should we tamper with nature to slow global warming?

In 2010 the earth's mean surface temperature was the warmest in 131 years. —NASA (2011)

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climate mitigation

Climate mitigation consists of actions to limit the rate of long-term climate change. Oceans are one of the most signifcant regulatory earth system with the ability to provide climate mitigation — the slowing of long-term climate change through biological and chemical action.

Proponents of geo-engineering have suggested methods such as spraying sea water into the air from ships to make seed clouds, which would reflect more sunlight back into space, and adding additional nutrients to the ocean to increase the uptake of CO_2 by biological action. Even if achievable in practice, both options are likely to have limited impact and may have negative environmental side effects.

Another geo-engineering option is direct injection of CO_2 into depleted oil and gas fields under the sea floor. This approach is anticipated to be commercially viable by 2015, and offers an estimated potential storage capacity approximately 30-40 times the current level of global CO_2 emissions. Even if geo-engineering on this scale could be achieved, there is concern about long-term safety. The potential future escape of stored gases carries significant risks, including increased ocean acidification and acceleration of global warming.

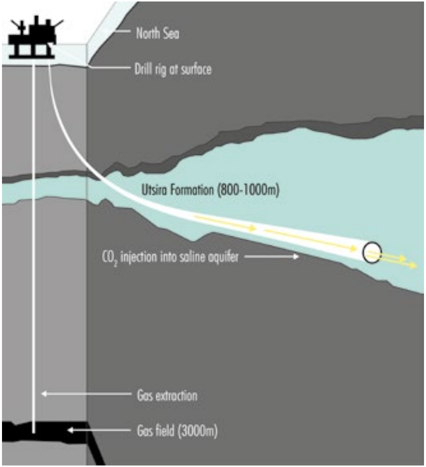

Fig 1: CO_2 sequestration from an existing offshore oil rig into a saline aquifer. Note that not all planned sequestration technologies use exhausted oil cavities, and some, like the one illustrated, tend to pump CO_2 into saline aquifers above existing fields.
[Statoil, 2005]

geoengineering

can we control the climate?

Los Angeles County is spending US$550,000 a year on cloud seeding to increase rainfall, a method estimated to provide drinking water for 36,000 people. —San Diego Union Tribune (2016)

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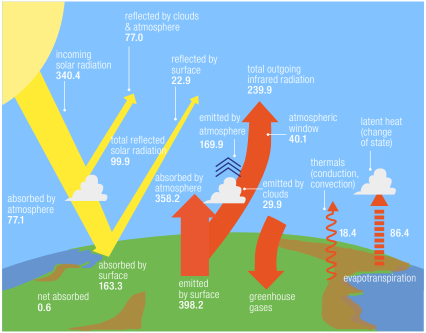
geoengineering

It is now understood that during the industrial period human beings inadvertently altered the climate via aerosol pollution; an increase in carbon-based greenhouse gases (GHG) traps heat near the earth's surface, gradually raising global temperatures. This effect is magnified by a simultaneous decrease in polar sea ice, reducing the amount of sunlight reflected into space (Fig 1). A question now under consideration is how large-scale climate manipulation projects (geo-engineering) could reverse or slow these warming trends.

Proposals to reduce the concentration of GHG focus on increasing uptake of these gases into natural carbon sinks such as trees and water. One concept suggests intensifying ocean absorption of carbon by increasing the productivity of marine life, accomplished by adding nutrients to ocean water, thus stimulating plankton growth.

Approaches to reducing the amount of received sunlight on earth include constructing orbital mirrors to create a 'reflective shield' (Fig 2), increasing ocean cloud cover via spray-based cloud seeding, and artificially polluting the upper atmosphere with sulfur dioxide aerosols to mimic the reflectivity of volcanic ash.



All values are average Wm^2 flux based on ten years of data

Fig 1: Earth's energy budget
[NASA, 2014]

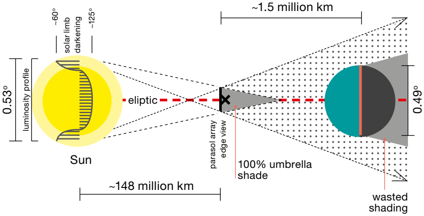


Fig 2: Space mirrors could provide the total planetary electrical demand projected for the year 2050
[Ultimax, 2014]

climate adaptation

is your city prepared for the impacts of climate change?

In 2013, the Rockefeller Foundation pledged US$100M to enable at least 100 cities around the world to hire resilience officers to improve response to climate change and other shocks. —Philanthropy News Digest, *Thirteen New Commitments Announced at 2013 Clinton Global Initiative Meeting* (2013)

climate adaptation

The UN estimates that between 2000-2013, direct losses from disasters globally were roughly US$2.5tn. Climate change increases the frequency and intensity of extreme weather events. Responding to and preparing for extreme weather patterns incurs both economic and societal costs. The charity Oxfam recently reported that between 2009 and 2014, approximately $490bn was spent on climate-related disasters on a global scale. A 2014 UNEP report on the state of climate change adaptation found that the global cost of adaptation is likely to be US$250–500bn by 2050, two to three times higher than original estimates by the Intergovernmental Panel on Climate Change (IPCC).

Given that extreme weather events are likely to increase in both frequency and severity, many governments and municipalities are developing strategies to prepare for the future, both in terms of mitigation and adaptation. In the wake of Hurricane Sandy, the Mayor of New York City outlined a US$20bn plan to protect the city from rising sea levels and powerful storm surges. Adaptation measures included building an extensive network of flood walls, levees and bulkheads along the cities shoreline. The City of Chicago is investing in permeable pavement and enlarging the size of its street tree wells to significantly increase stormwater absorption.

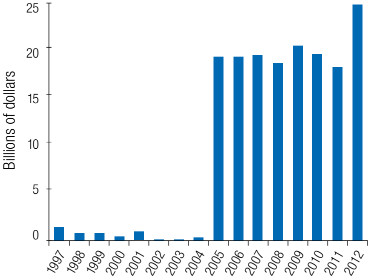


Fig 1: National flood insurance programme debt post Hurricane Katrina
[White House Federal Budget and Congressional Research Service, 2013]

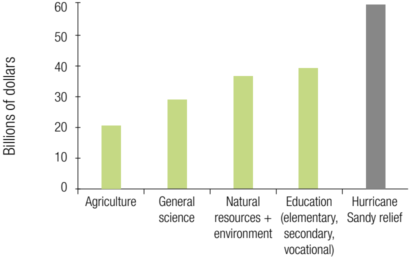
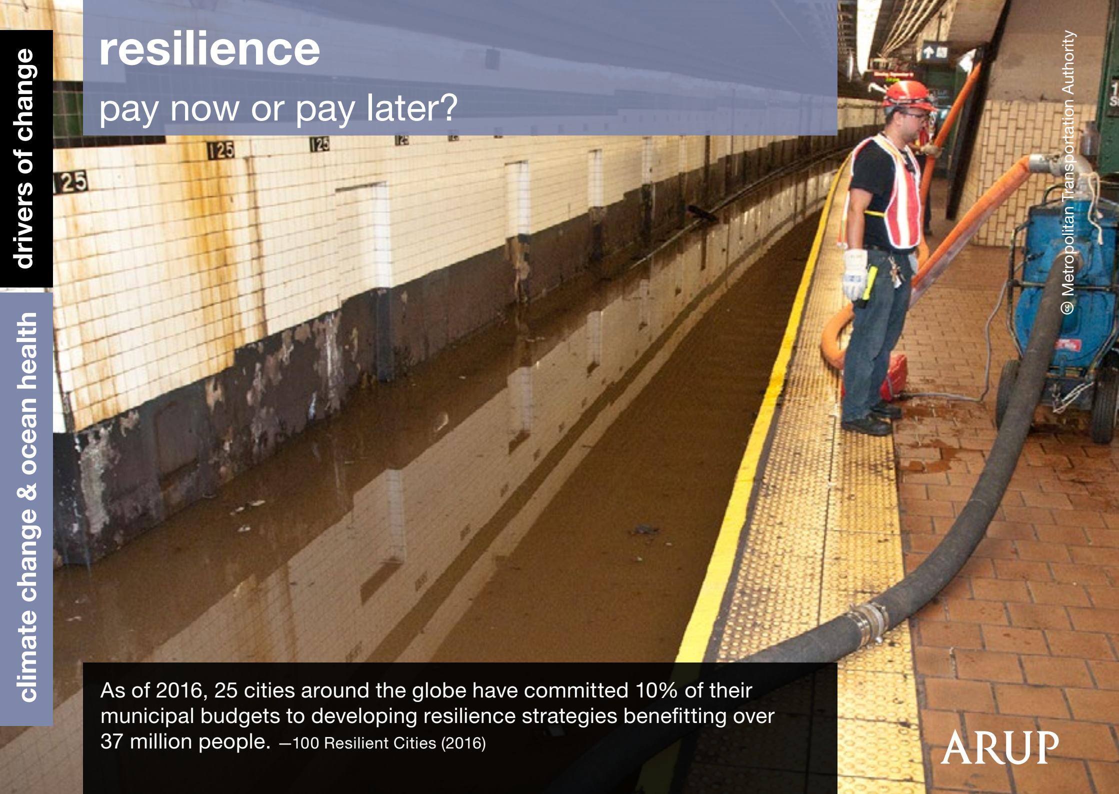


Fig 2: 48-hour hurricane relief vs 2012 Federal budgets
[White House Federal Budget and Congressional Research Service, 2013]


drivers of change
climate change & ocean health
resilience
pay now or pay later?
125
© Metropolitan Transportation Authority
As of 2016, 25 cities around the globe have committed 10% of their municipal budgets to developing resilience strategies benefitting over 37 million people. —100 Resilient Cities (2016)
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resilience

Resilience is the capacity of people, cities and the built environment to survive and thrive when encountering natural and human pressures. Resilience is both proactive and reactive; it must recognize the complex and interdependent effects of climate change. Individuals, communities and systems use resilience to adapt and grow in the face of shocks (e.g. earthquakes, floods and storms), as well as chronic stressors (e.g. unemployment, social unrest and ongoing water shortages).

Since 1900, worldwide economic losses due to natural disasters have been increasing (Fig 1), with 30% of global losses due to flooding, 26% from earthquakes and 19% from storm damage. Hurricane Katrina, which made landfall in the southern US in 2005, was the most destructive weather event in US history (Fig 2). Nearly 2000 people died as a result of the storm, which caused US$108 million in damages, flooded 80% of the city of New Orleans and displaced over 1m residents of the Gulf Coast region. It is estimated that by 2050, between US$66–$106bn worth of US coastal property will be below sea level.

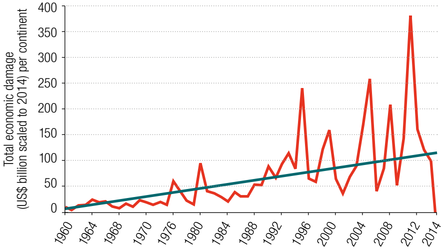


Fig 1: Global total natural disaster induced economic damage 1950–2015
[Emdat, 2015]

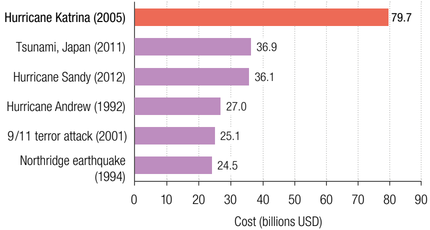
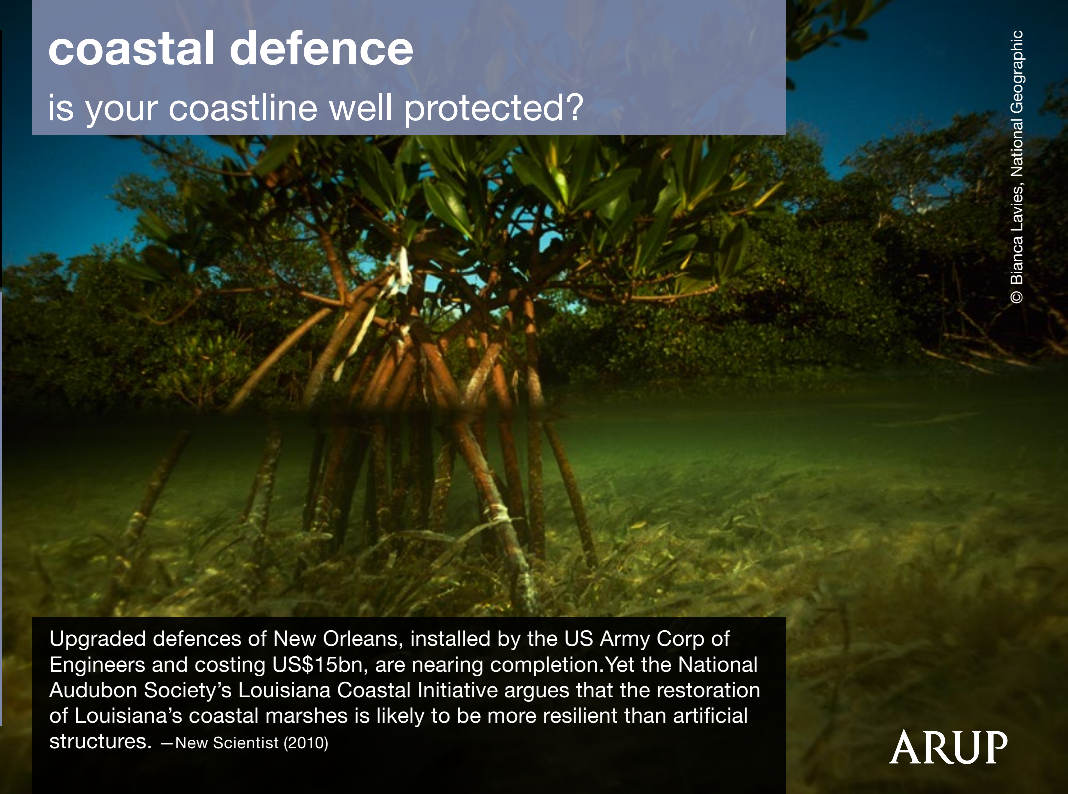


Fig 2: Catastrophes with highest insurance costs 1970–2015
[Swiss Re, 2015]

coastal defence

is your coastline well protected?



Upgraded defences of New Orleans, installed by the US Army Corp of Engineers and costing US$15bn, are nearing completion. Yet the National Audubon Society's Louisiana Coastal Initiative argues that the restoration of Louisiana's coastal marshes is likely to be more resilient than artificial structures. —New Scientist (2010)

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coastal defence

Coastlines naturally erode and build up over time. The rate of erosion and deposition is heavily influenced by the presence of natural and man-made coastal defences. In northern Europe, some unprotected coasts erode at rates of over 1m per year, and in other parts of the world coastal areas are destroyed within hours by increasingly frequent extreme weather events.

Natural coastal defences, such as coral reefs, wetlands and mangroves, protect coastlines and the land immediately inshore. They support valuable ecosystems and are often more effective than man-made defences at mitigating the impacts of extreme weather. Such defences can be “soft engineered” to increase their presence and effectiveness.

In contrast “hard” defences, such as sea walls and levees, often reduce the land’s natural capacity to absorb extreme weather and generate greater erosion further along the coastline. Adjustable hard defences, like the Eastern Scheldt in the Netherlands, are seen to offer the best short term solution when used in conjunction with natural systems. The project is part of a broader national initiative led by the Sustainable Coastal Development Committee to ensure long-term protection of the Dutch coast and its hinterland.

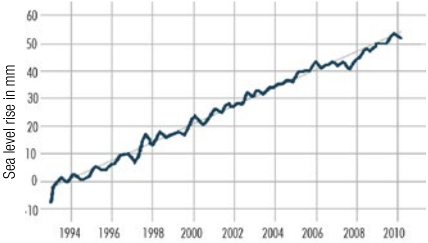

Fig 1: Sea level rise from 1994-2010. The sea level is expected to continue to rise 1.7mm per year
[CLS/Cnes/Legos, 2010]

Delta	Pressure on space	Flood vulnerability	Freshwater shortage	Ageing/inadequate infrastructure
Yellow River delta (China)	••	•	••	•
Mekong River delta (Vietnam)	••	••••	••••	••
Ganges–Brahmaputra delta (Bangladesh)	••••	••••	••	••
Nile River delta (Egypt)	••••	•	••••	••••
Rhine River delta (The Netherlands)	•••	••	••	•••
Mississippi River delta (USA)	•	••••	•	••••

• relatively minor problem, now and in the near future
•• currently a minor problem, but is likely to increase in the near future
••• currently already a big problem, future trend uncertain
•••• currently already a big problem, likely to increase in the near future

Fig 2: Impact of climate change on deltas around the world
[World Water Council, 2010]

drivers of change

climate change & ocean health

marine energy

could the oceans power our world?

Oceans account for approximately 70% of global solar energy and almost 90% of total wind energy. —WBGU (2006)

ARUP

marine energy

The oceans offer a variety of energy forms. "Marine energy" can be extracted from waves, tidal range, salinity gradient and temperature differences. The more general term "offshore energy" includes wind turbines since the oceans provide access to a vast wind resource.

Compared to the conditions for land-based wind turbines, wind at sea is stronger and more consistent. Offshore wind capacity is growing rapidly, initially for wind turbines fixed to the seabed in shallow water. They are being installed in coastal urban areas, where there is a strong demand for electricity, such as the planned 1000 MW London Array in the outer Thames Estuary. This proximity allows the optimisation of costs linked to transmission and the congestion of the grid. Floating wind turbines have even higher development potential.

The variable output of offshore wind power is well complemented by tidal range and tidal stream power which are more predictable and reliable, though opportunities for these are only near the coast and are site-specific. Examples in the UK are the Severn Barrage scheme proposal for tidal range and the first commercial installation in 2008 of 1.2 MW of tidal stream turbines in Strangford Lough in 2008.

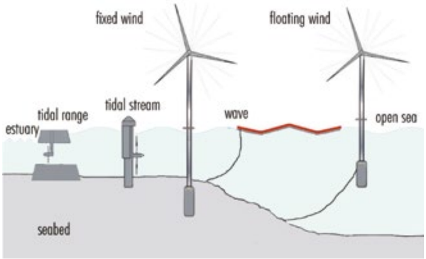

Fig 1: Types of offshore energy technology
[Roberts, 2010]

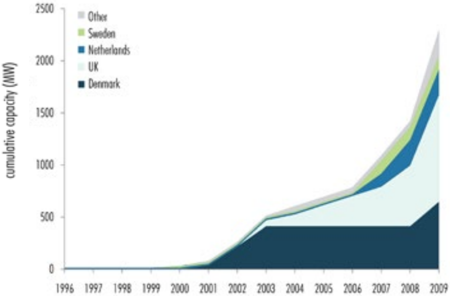

Fig 2: Development of fixed wind-turbine capacity
[Garrad Hassan, 201]

business opportunities

how will your business profit?

S&P 500 companies that are actively managing and planning for climate change secure an 18% higher return on investment than companies that aren't — and 67% higher ROI than companies who refuse to disclose their emissions. —CDP (2014)

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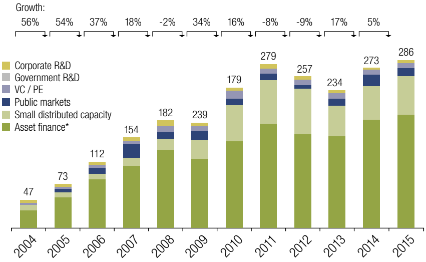
business opportunities

Companies are realising the business and market differentiation opportunities of climate change. A recent Carbon Trust study found that while 76% of executives believe the impacts of climate change present a potential risk to their businesses, a higher proportion (84%) believe that climate change represents increased opportunity in the future.

Eco-innovation, investment and resilient business models are on the rise (Fig 1), and are projected to drive further economic opportunity. Growth in eco-patents outpaced all other patent applications in many countries, with China, India and Korea leading the way (Fig 2). A new global index of companies leading the way in climate change mitigation outperformed the Bloomberg World Index by 9.6% between 2010 and 2014. These firms reported that investments to cut CO_2 led to average emissions reductions of 9% per company, while achieving an average internal rate of return of 57% per project. Carmaker General Motors redesigned delivery routes and switched deliveries from road to rail, helping cut emissions by 244,000 metric tons a year and saving the company US$287m.



*Asset finance volume adjusts for re-invested equity.
Total values include estimates for undisclosed deals

Fig 1: New investment in renewables 2004–2015
[UNEP, 2016]

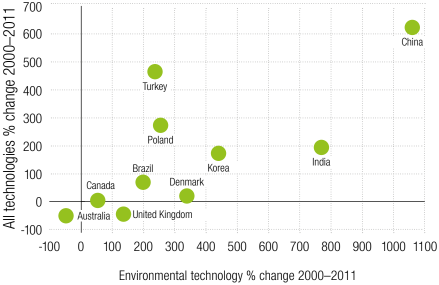


Fig 2: Environmental patents vs all technological patents
[OECD, 2016]

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