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Emerging Issues of Environmental Concern

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Emerging Issues of Environmental Concern

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Foreword

This planet and its people face a growing number of challenges. They are as diverse as our cultures and environments, but they can all be tackled through a combination of science, policy and action. The Frontiers 2017 report highlights emerging challenges for decision makers from government, business and civil society and provides them with the knowledge and options to act quickly.

A global network of scientists, experts and institutions has identified the issues in this report as having the potential to hugely impact society, economy and the environment. Some are long standing, but have not been paid enough attention, like the land mismanagement and desertification causing sand and dust storms and displacement. Some are persistent, for which new solutions and tools are emerging, like protected areas that benefit for marine and coastal resources or reliable, affordable energy solutions. And some are emerging from new scientific findings that warrant urgent intervention, like the rapid uptake of nanomaterials and growing resistance to antibiotics.

For example, a facility in the city of Patancheru near Hyderabad, India treats wastewater from 90 drug manufacturers every day. The discharge is then released into the Isakavagu stream, which feeds many rivers. However, when a research team led by Professor Joakim Larsson analyzed the discharged water, the concentration of a broad-spectrum antibiotic, ciprofloxacin, was enough to treat 44 000 people daily. This is not an isolated case. Around the world, discharge from municipal, agricultural and industrial waste in the environment means it is common to find antibiotic concentrations in many rivers, sediments and soils. It is steadily driving the evolution of resistant bacteria: a drug that once protected our health is now in danger of very quietly destroying it.

Now is the time for national and local governments, the business sector and civil society to tackle these emerging threats to the health of this planet and its people. I hope the report will inspire coordinated policies, strategies and action to turn these risks into opportunities as we work towards a pollution free planet and a prosperous future.

Erik Solheim
Head of UN Environment

Introduction

The Frontiers 2017 report presents six emerging issues of environmental concern with global implications. Antimicrobial resistance has emerged on the international agenda as an issue threatening public health and sustainable development. During the United Nations General Assembly in September 2016, Heads of State recognized the urgency of the situation as the numbers of communicable diseases that are evolving resistance to existing drugs are increasing at accelerating rates. Heads of State pledged their commitment to address the root causes of antimicrobial resistance across sectors, particularly in the fields of human health, animal health and agriculture. A less well known but significant factor is the role of environmental components in amplifying resistance. Domestic and agricultural solid waste and wastewater often end up in the natural environment. The natural environment thus becomes a reservoir of antibiotic residues, resistant pathogens and other molecules with antimicrobial properties that enhance the spread of resistance genes in microbial communities. Through this report, UN Environment aims to illuminate the environmental dimension of the issue and emphasize the need for considering the environmental exposure to antimicrobials in efforts to curb the resistance.

Nanomaterials have entered rapidly into many aspects of our daily life. Some, such as nanosilver, can act as antimicrobial agents. Nanomaterials are ever present in what we regularly consume, ranging from food products, cosmetics, disinfectants, kitchenware, baby goods, clothing, fabrics, furniture, electronics and appliances. While nanotechnology has been emerging for some decades, ongoing research now allows us to manufacture conventional materials at a miniscule scale. The unique properties that come with engineered nano-sized materials offer incredible applications. However, questions have arisen—and remain only partially answered—about the health risks of these novel materials. What we have learned with other hazardous substances that possess similar size, shape and chemistry may provide some lessons about how to manage exposures, assure the safety and, at the same time, enjoy the many benefits of nanomaterials.

At the United Nations Ocean Conference in June 2017, Member States reaffirmed their obligation to conserve and responsibly use the oceans, seas and marine resources for sustainable development. Promoting the use of effective and appropriate area-based management tools, such as marine protected areas, was among the renewed pledges. Marine protected areas offer one of the best options for maintaining healthy oceans. In the last decade, countries around the world have progressively taken actions to designate new, or to enlarge existing, marine protected areas to safeguard natural resources and ecological functions. To date, around 14.4 per cent of the world's coastal and marine areas under national jurisdictions are declared protected. This signals the commitment of the global community to safeguard these precious ecosystems. For marine protected areas to be truly effective, however, they also require strong governance that involves relevant users and stakeholders, influences their behaviour, and ultimately reduces the impacts that result from extractive practices. Effective sharing of costs and benefits of marine protected areas is an essential step to ensure genuine sustainable development.

Sand and dust storms are another environmental issue with global implications—causing chronic health problems, damage to agriculture and infrastructure, intensified soil erosion, and economic losses that reach millions of dollars every year. Sand and dust storms are connected to a range of environmental and development issues that extend across national, regional and continental boundaries. Analyses found increased frequencies of dust storms in some parts of the world. Moreover, there is a strong link between the unsustainable use of land and water and the increase in dust emissions. Integrated strategies that promote sustainable land and water management, ecosystem restoration and climate change adaptation can help reduce and mitigate the threats that originate from sand and dust storms over the long term.

In 2015 renewable energy has overtaken coal in terms of installed capacity to produce power. Much of the growth is attributed to solar energy. An estimated half a million solar panels were installed each day. In parts of Africa and Asia where access to reliable grid electricity remains a challenge, stand-alone pico-solar photovoltaic systems have rapidly gained popularity among off-grid communities in both rural and urban areas, particularly in informal settlements. Their popularity is driven by the drastic drop in price for equipment and service, as well as innovative microcredit schemes and mobile phone banking capabilities. While the adoption of small-sized solar power systems may not be a long-term solution to the overall issue of electrification and energy disparity, it is one of many alternative development paths that help us avoid future carbon emissions.

In 2016, about 31.1 million people were newly displaced within their own countries because of conflicts, violence and natural disasters—the latter responsible for 24.2 million of them. The sudden-onset of natural disasters, such as storms and floods, and the slow-onset of environmental change and degradation, including desertification and sea level rise, can make areas uninhabitable, and displace populations temporarily or permanently. The increased awareness of risks from a changing environment and climate reinforces the need for good planning for in-place adaptation and policy design to prevent or manage human displacements.

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Antimicrobial Resistance: Investigating the Environmental Dimension

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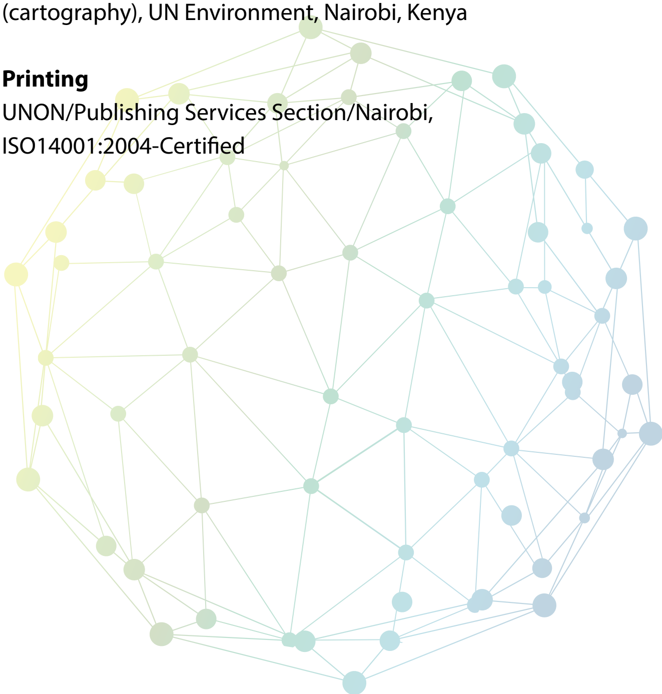
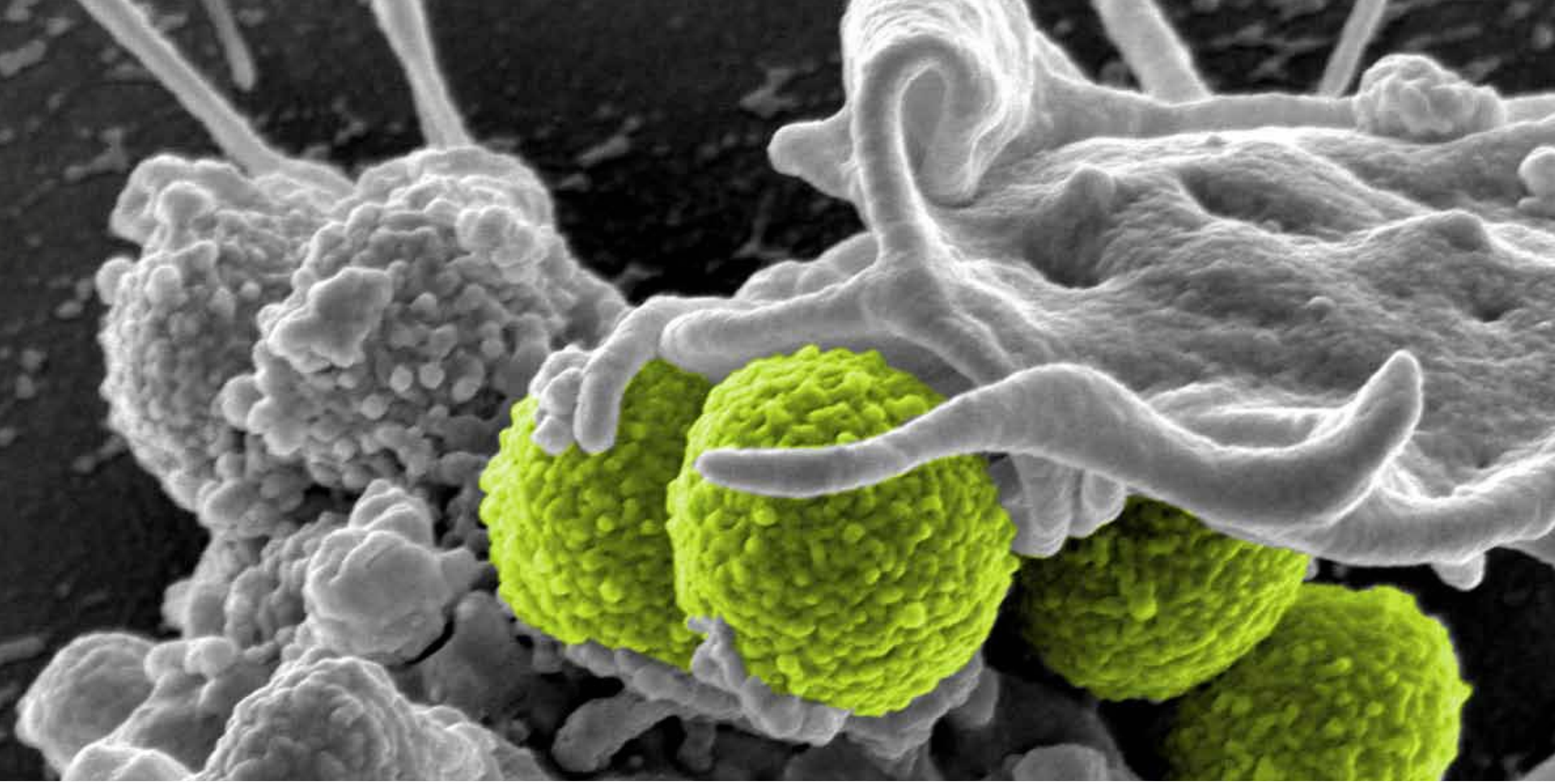




Four methicillin-resistant Staphylococcus aureus bacteria being enveloped by a human white blood cell
Credit: US National Institute of Allergy and Infectious Diseases

Antimicrobial Resistance: Investigating the Environmental Dimension

What is antimicrobial resistance?

According to the World Health Organization, we may be entering a post-antibiotic era when simple, and previously treatable, bacterial infections can kill and when routine medical procedures, such as joint replacements and chemotherapy that rely on antibiotic preventative treatment, will no longer be possible.[1] The 2014 O'Neill report commissioned by the UK government estimated that antimicrobial resistant infections may become the leading cause of death globally by 2050.[2]

Antibiotic pharmaceuticals are used around the world to treat and prevent bacterial infections in humans, animals and even plants. They have also been used widely as growth promoters to increase meat production, although this practice was banned in the European Union in 2006.[3,4] While the misuse of antibiotics in medical and agricultural practices has been linked to increasing resistance, the role of the natural environment in the emergence and spread of resistance has received relatively little attention.

Resistance to antimicrobials can be intrinsic or acquired. Acquired resistance can occur through a mutation in bacterial DNA or by gaining the resistance genes through horizontal gene transfer when DNA moves from one bacterium to another. Acquired resistance that leads to failure of infection treatments in clinical and veterinary settings is currently a subject of concern.

Many antibiotics are natural, such as the original penicillin found in bread mould, while many are synthesized or chemically modified from natural antibiotics for enhanced activity and stability.[5] Antibiotics are a subset of antimicrobials—substances that kill or suppress the growth of microorganisms. The terms are commonly used interchangeably.

Competition always occurs between microorganisms by way of producing antibiotic molecules to inhibit others from thriving. For bacteria to survive, they have successfully developed mechanisms to resist the antibiotic assault. Research indicates that resistance to antibiotics, including some utilized in modern medicine, has existed for millions of years, suggesting that antibiotic resistance is natural, ancient, and hard wired in the shared genome of microbes.[6]

Without human interference, selection for resistance already occurs naturally in microbial populations in soil, water and other habitats. However, current antibiotic use in the hundreds of thousands of tons per annum and subsequent release of antibiotic residues into the environment produce a step change in the magnitude of selection pressures that lead to the increase in antibiotic resistant bacteria.[7] Once consumed, most antibiotic drugs are excreted unmetabolized, along with resistant bacteria. They can then pass either through sewage systems or more directly into water and soils, and mix with environmental bacteria in the presence of other pollutants that may add further pressure to help select for antibiotic resistance, directly or indirectly. The extent to which the environment contributes to this problem is under intense investigation, but the answers will in part depend on the level of environmental contamination, and how long antimicrobial residues persist in an active form.

Bacteria in water and soil naturally possess a huge diversity of resistance genes. Research has found that previously susceptible pathogens are able to acquire resistance genes from environmental bacteria.[8-11] The genetic basis of antibiotic resistance in bacteria and how resistance can spread between environment and clinic are now subjects of enormous interest.[11-13]

Human exposure to environmental bacteria and to antibiotic resistance genes can take place through drinking water, food consumption or through direct contact with the environment. A further question is to what extent transmission of resistant bacteria occurs through the food chain or by direct contact with the environment. For instance, research showed that, even with high levels of investment in wastewater treatment, an estimated 6 million exposure events to one type of antibiotic resistant *E. coli* occur each year in the United Kingdom's coastal recreational waters.[14] There are also well-documented cases of the evolution of antibiotic-resistant bacteria within food animals with subsequent spread to humans.[15]

What is an antimicrobial?
Any substance of natural, semisynthetic or synthetic origin that kills or inhibits the growth of microorganisms, such as bacteria, viruses, protozoa and fungi. Antimicrobial substances are used in the form of pharmaceutical drugs such as antibiotics, antivirals and antifungals; or of chemicals such as antiseptics, disinfectants, and sterilants.

What is an antibiotic?
An antimicrobial substance naturally produced by bacteria or fungi that can kill or inhibit the growth of other microorganisms. People make use of many types of antibiotics as medicines to prevent and treat infections caused by pathogenic bacteria, fungi and certain parasites. The majority of antibiotics are primarily used against bacteria.

Because antibiotics are a type of antimicrobials, the two terms are often used interchangeably.

What is antimicrobial resistance?
Antimicrobial resistance occurs when a microorganism evolves to resist the effects of an antimicrobial agent and multiply in its presence. Globally about 700 000 people die of resistant infections every year because available antimicrobial drugs have become less effective at killing the resistant pathogens.

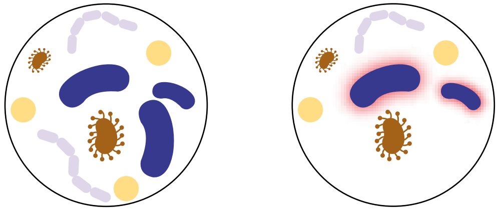
What is selection for resistance?
Natural selection is a mechanism which drives adaptation of organisms to better survive in their environment in order to thrive and multiply. In the context of antimicrobial resistance, antimicrobial substances exert a selective pressure on microbes that drive evolution of resistance. Those able to resist the effects of antimicrobials survive and reproduce, whereas susceptible ones are killed or their growth is inhibited. Overuse and misuse of antibiotics increase selection for antibiotic resistance among bacteria.

Antibiotics, co-selectors and resistant bacteria in the environment

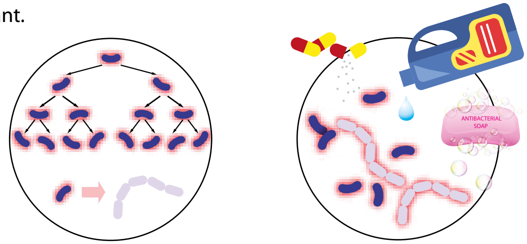
The discharge of antibiotics and other antimicrobial compounds, such as disinfectants and heavy metals, into natural environments has the potential to drive the evolution of resistant bacteria. These compounds are present in waters and soils at a wide range of concentrations, depending on source and behaviour in terms of degradation rate and adsorption to solids.[16,17] Municipal wastewater contains a vast array of contaminants: pharmaceuticals and personal care products from households; hospital waste with high concentrations of antibiotics and disinfectants; and compounds from industrial activity, including heavy metals. Some pharmaceutical production facilities discharge very large amounts of antibiotics directly into the environment, resulting in concentrations up to or exceeding levels used to treat infection in humans.[18,19] The elevated level of resistance found in the discharge vicinity is definitive evidence that selection for antibiotic resistance occurs in polluted environments.[20] However, antibiotic concentrations in most effluents, surface waters and soil environment could be 1 000 times lower than levels used in the clinic or raw industrial effluent.[16] It is the low-concentration contamination that is of particular importance—the concentration is too low to be lethal to exposed bacteria, but sufficient to select for resistance.[21] The question is where is the threshold at which antibiotics have no selective effect on microbial communities. At low antibiotic concentration, the acquisition of resistance may be reliant more on gene transfer from another bacterium, known as horizontal gene transfer. Therefore, single species studies of bacteria on agar plates are unlikely to give meaningful insights about the development of resistance in complex microbial communities present in the natural environment.

Concentrations in river water depend on wastewater treatment facilities as well as antibiotic use in the populations they serve. Treatment plants are generally designed to remove conventional pollutants, such as nutrients, organic matter, suspended solids and, to some extent, pathogens, but not antibiotics.[22] Agricultural waste such as animal manure may also contain concentrations of antibiotics in the same order of magnitude as are used to treat infection. However, after adsorption to soil particles, some antibiotics get neutralized, while some remain active and exert a selection pressure on

Natural selection and antibiotic resistance



In the microbial world, competition always occurs between organisms by way of producing antibiotic molecules to inhibit others from thriving. Susceptible organisms perish. However, bacteria and fungi are known to have developed defence mechanisms to resist the antibiotic attack and survive, or in other words, become antibiotic resistant.

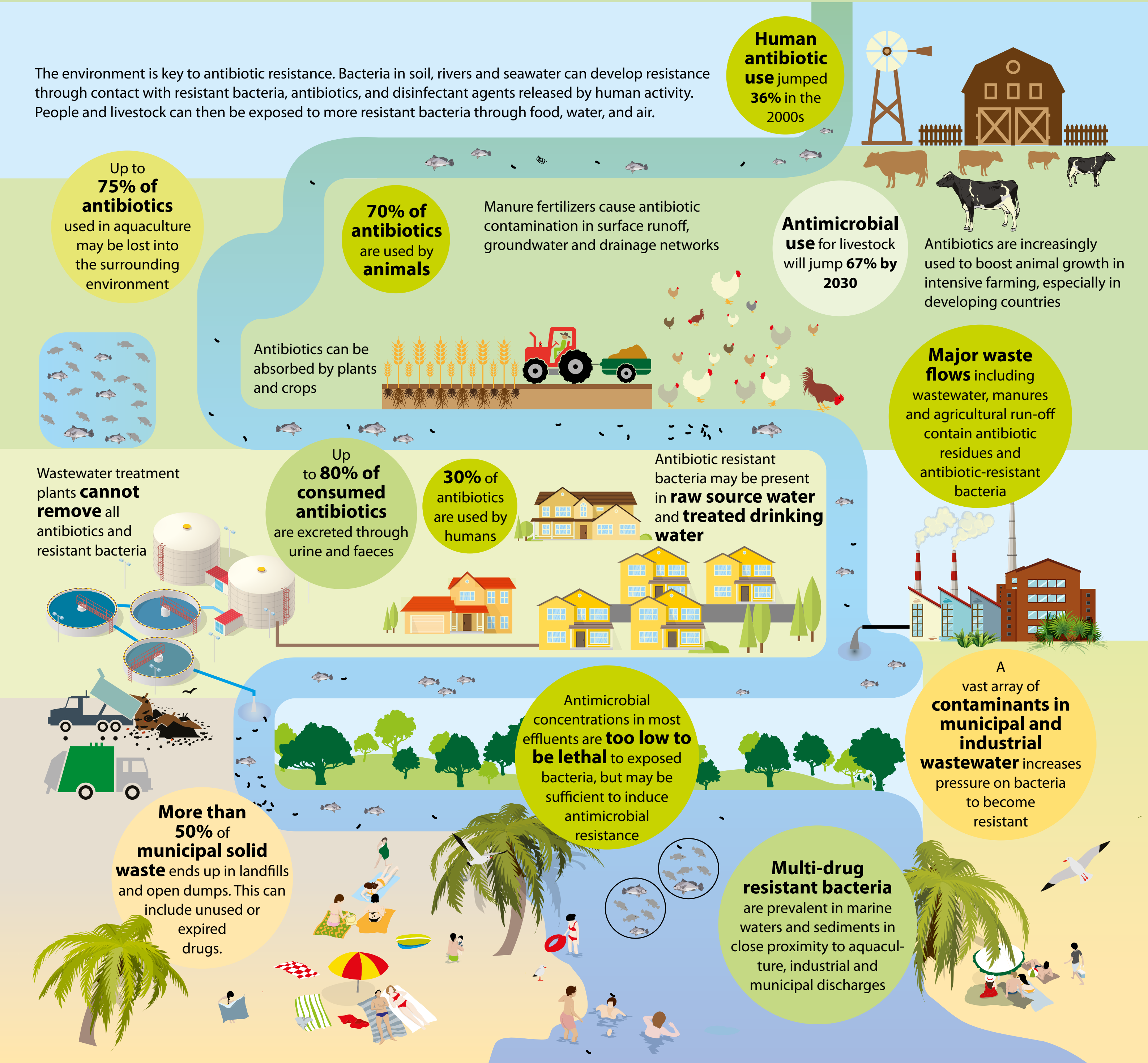


Resistance genes can pass to the next generation, and even between un-related bacteria via horizontal gene transfer. Overuse and misuse of antibiotic drugs as well as increased exposure to antimicrobial substances in the environment increases selection for antibiotic resistance among bacteria.

Video: Antibiotics and the environment: The quiet crisis

Link: www.youtube.com/watch?v=WSIrKEUxsPs *© McMaster University*

Antimicrobial resistance and the environment



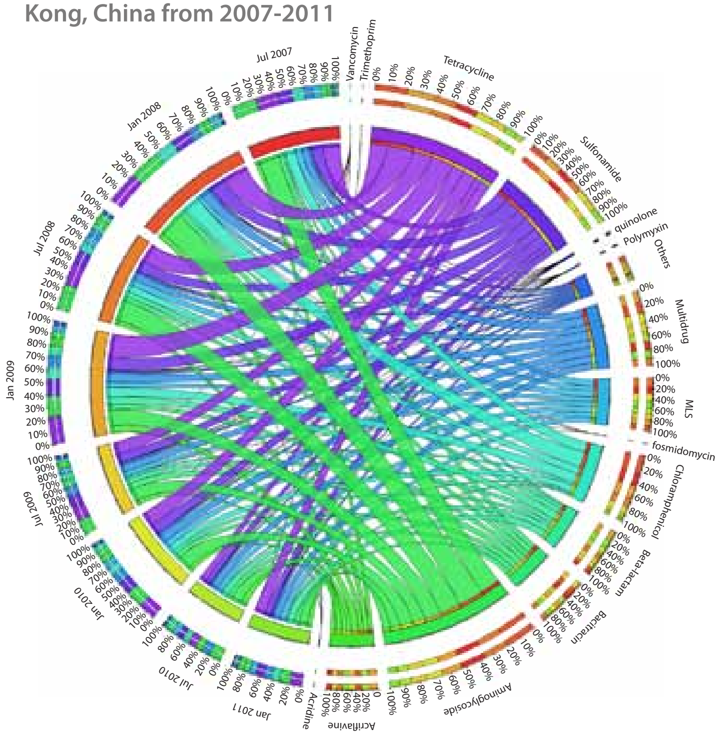
Video: Bacterial resistance and its impact on health

https://www.youtube.com/watch?v=eDhhv31vuV8 *© University of Exeter*
Photo credit: James Gathany

bacteria in soil.[23] Generating reliable temporal and spatial data on the exposure of microbial communities to antimicrobial residues in soil and water is vital to better understand the extent of selection that occurs in natural environments.[24,25] The matter is further complicated by mixtures of antibiotic residues and other pollutants, which may combine to produce increased selection pressures compared to individual substances.[26] Evidence for indirect or co-selection for antibiotic resistance is accumulating for heavy metals such as silver, cadmium, copper, mercury and zinc, and for compounds with antimicrobial properties such as disinfectants and biocides.[26-30] Heavy metals are ubiquitous in agricultural, industrial and urban environments. Therefore, it is likely that antimicrobial resistance may rise in exposed bacteria even when direct selective pressure from antibiotics is absent.

Because antibiotics and antibiotic-resistant bacteria come from the same source, they are often found together. Major waste flows including wastewater, animal manures and agricultural run-off also contain antibiotic-resistant bacteria. The discharge of untreated sewage is likely to be an important driver of increasing antibiotic resistance in the environment, however it is a very challenging problem to solve. Even in countries with high wastewater treatment investment and management strategies to reduce aquatic pollution from farming, large variations in numbers of antibiotic resistant bacteria are still found within river catchments. Conflicting results have been found regarding the ability of wastewater treatment to reduce the amount of antibiotic resistant bacteria in effluent, with some studies showing efficient removal and others finding increased numbers of resistant bacteria in effluent compared to influent.[22] The latter results suggest that wastewater treatment plants may be hot spots for horizontal gene transfer due to high bacterial density and nutrient richness.[31,32] Therefore, wastewater and sewage sludge are important surveillance tools, allowing assessment of the abundance of antibiotic resistant bacteria and resistance genes in the human population.[33,34]

Abundance of antimicrobial resistance genes in activated sludge from the Shatin wastewater treatment plant in Hong Kong, China from 2007-2011



Courtesy of Prof. Tong Zhang, University of Hong Kong *See also Yang et al. (2013)*[33]

The crisscrossing lines illustrate the abundance of resistance genes in eight sludge samples. The thicker the line is, the more abundant the class of resistance genes. For instance, genes resistant to aminoglycoside and tetracycline are the most dominant types detected in all samples.

Mitigating the discharge of antimicrobials into the environment

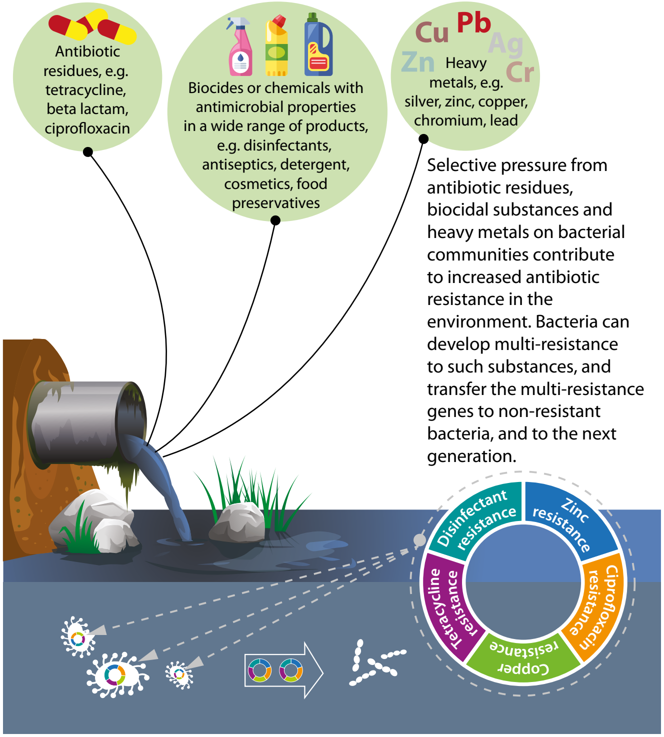
Current regulatory policies have been slow to properly consider discharge of antibiotics and antibiotic-resistant bacteria. Growing awareness of the potential for antibiotic residues to damage aquatic organisms has led to three antibiotic compounds being placed on the European Union Watch List of emerging water pollutants in 2015.[35] There are voluntary initiatives to reduce effluent concentrations of antibiotics by some drug manufacturers.[25] In September 2016 several leading pharmaceutical companies signed an antimicrobial-resistance roadmap presented to the United Nations with the environmental management of antibiotic-related production as a central theme.[36]

Some co-selecting compounds such as triclosan, used in a wide range of consumer products, have been banned or restricted in various markets. The Association of Southeast Asian Nations has put a restriction on the maximum concentration of triclosan in cosmetic and personal care items.[37] The United States' Food and Drug Administration ruled in 2016 that over-the-counter antibacterial products containing triclosan and 18 other compounds should no longer be marketed due to findings that long-term exposure to these active ingredients could pose health risks such as bacterial resistance or hormonal effects.[38]

Increased regulation of antibiotics, and of co-selective compounds, could drive the development of affordable mitigation and risk reduction solutions and stimulate discussion of responsibility for antibiotic residues and for the resistant bacteria they engender. Arguably, the antibiotic manufacturers, prescribers, farmers and even patients bear some responsibility for the damaging effects of antibiotic residues that reach the environment. Such significant changes in the way we tackle antibiotic resistance, particularly in the context of a One-Health approach, could transform incentives to reduce antibiotic use and to improve waste management practices.

Many mitigation strategies already exist that reduce or remove antibiotics and resistant bacteria from waste streams entering the environment: secondary and tertiary

Co-selection of resistance to antibiotics, metals and biocides



Video: Why did the FDA ban antibacterial soap?

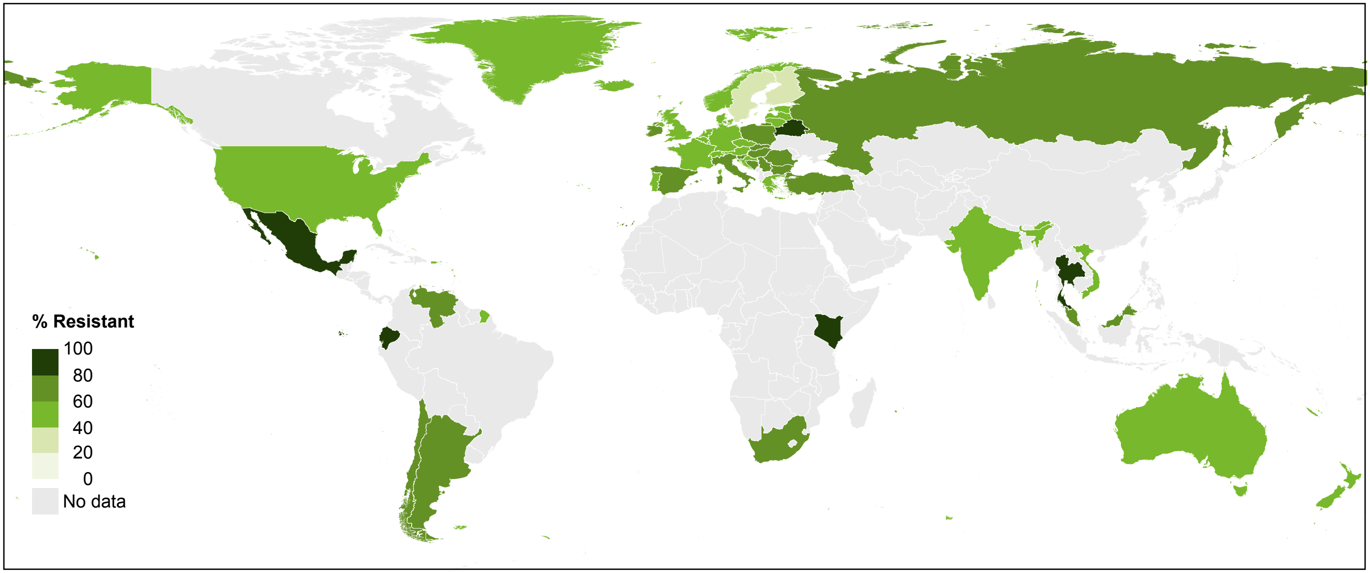
Link: www.youtube.com/watch?v=9dExiRwh-DQ *© SciShow*
Photo credit: Galushko Sergey/Shutterstock.com

wastewater treatment; membrane filtration and ozonation that remove antibiotics and bacteria; and UV disinfection and heat treatment, which are even more effective at removing viable bacteria. These approaches have variable levels of effectiveness and some can produce unintended consequences, such as toxic by-products. Treating animal waste before application to land and simple methods to reduce aquatic pollution can also be used. Barriers to these approaches are largely financial and relate to the ability or desire of societies to change. There is an urgent need to better understand the risks posed by antimicrobial resistance in the environment and to develop sustainable mitigation technologies.

It has been argued that the complexity of the problem is so great as to be unfathomable, considering the likelihood of interactions among unimaginable numbers of bacteria with a seemingly endless facility for gene transfer, the complex mixtures of selecting compounds, and the diversity of resistance-building mechanisms.[39] With sufficient data this is probably untrue, but the question remains whether we have time to wait for enough data to be generated before making decisions.

We know that wherever human activity occurs increased levels of antibiotics and antibiotic resistance emerge in the environment. We know that under laboratory conditions some antibiotics select for antibiotic resistance even at concentrations found in the natural environment. We also know that clinically important resistance genes that have recently emerged in pathogens originated in bacteria from the natural environment. Data are already available that show transmission is likely to occur via the food chain and through exposure to polluted environments. There is often a call for evidence-based decisions; but with a problem as complicated as antibiotic resistance, how much evidence is enough? Acquiring sufficient evidence of the type generated by clinical trials may be impossible or such a challenging task that we risk huge delays in the regulation of antibiotic use and implementation of mitigation strategies.

Percentage of invasive *E.Coli* isolates resistant to Aminopenicillins



Courtesy of The Center for Disease Dynamics, Economics & Policy (CDDEP). For more resistance maps, visit http://resistancemap.cddep.org/AntibioticResistance.php

Future research and activities to inform policy

Antibiotic resistance is increasingly found in clinically important pathogens, livestock production is intensifying in response to growing demand, and population growth and rapid urbanization are producing more pollution. Together these trends suggest that processes driving the proliferation of antibiotic resistance will continue for the foreseeable future, unless concerted and globally coordinated action intervenes. Hopefully, these trends will provoke us to better manage the issue and enable policies that take the critical roles of the natural environment into consideration.

Precautionary measures might include reducing the overall release of antibiotics, and of co-selecting compounds, into the environment by more controlled and judicious use as well as by tackling critical hotspots such as hospitals, drug manufacturing sites, wastewater treatment plants, and agricultural sources through improvements in sewage and wastewater management. Further precautions include ending the use of antibiotics as growth promoters in animal husbandry; minimizing the use of household and personal care products containing antimicrobial substances; and encouraging technological innovations that ensure newly developed antibiotics break down rapidly after providing their beneficial effects.

Responsible policies must be informed by fundamental research into the contribution of antimicrobial and co-selecting chemical contamination in the natural environment to overall levels of antimicrobial resistance, as well as the evolution and transmission of resistance. For instance, research on the fate of antibiotic residues upon contact with soil helps regulatory bodies understand which antibiotics remain bioactive—capable of exerting selective pressure—and therefore require more attention.[23] Similarly, gaining insights into the capacity of antimicrobials to select for resistance in aquatic environments can help us design more effective regulatory measures and wastewater management strategies based on the selection effects, rather than on discharge concentration. Communication of the findings to a wider audience is vitally important in increasing awareness of the issue among the public, policymakers and community leaders.

Welcoming Citizen Engagement to Monitor Antimicrobials in the Environment

To reduce further antimicrobial resistance, researchers need to understand how bacteria encounter antimicrobials and co-selecting compounds in diverse environments and how such exposure unfolds for the emergence and spread of resistance. Many challenges–such as time, resource and data limitations–impede our ability to answer such fundamental questions.

Recruiting help from civil society could complement the professional scientific and technical workforce, and including their contributions will make them part of the solution as well as build awareness. Involving various stakeholders across sectors could address data gaps and offer opportunities to gain new insights. It can help scientists to detect hotspots of antimicrobial pollution, map out patterns and identify intervention strategies.

For instance, online tools could motivate farmers to enter data on the types and amounts of antibiotics they are using and provide information regarding how antibiotic-contaminated wastewater is disposed. Interested consumers can enter data on their antibiotic use, disposal of expired drugs, or use of household products with antimicrobial properties. High school students can collect soil and water samples, or even fecal samples from indicator species of animals, for analysis in projects guided by scientists.[40,41] Campaigns could be devised that host dedicated hackathon events, attracting programmers to help develop new tools such as phone apps for chemical identification and statistical analysis on concentrations and trends in timing.

When antibiotic treatment fails because of resistance, the response is to use more antibiotics. This has led to overuse and perennial demand for new antibiotics to replace those that are no longer effective. When medical doctors and veterinarians are confronted with infected patients who would benefit from antibiotic treatment, concern over antimicrobial resistance in the natural environment is not their priority concern. Nevertheless, viable antibiotics, co-selecting compounds and resistant bacteria must be prevented from entering the natural environment where they may foster emergence of new resistance genes. Without prevention, we will be at direct and significant risk of exposure to environmental reservoirs of antimicrobial resistant pathogens.

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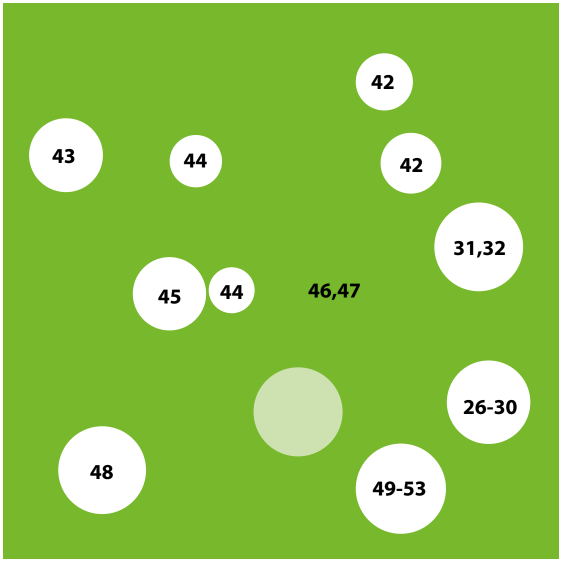

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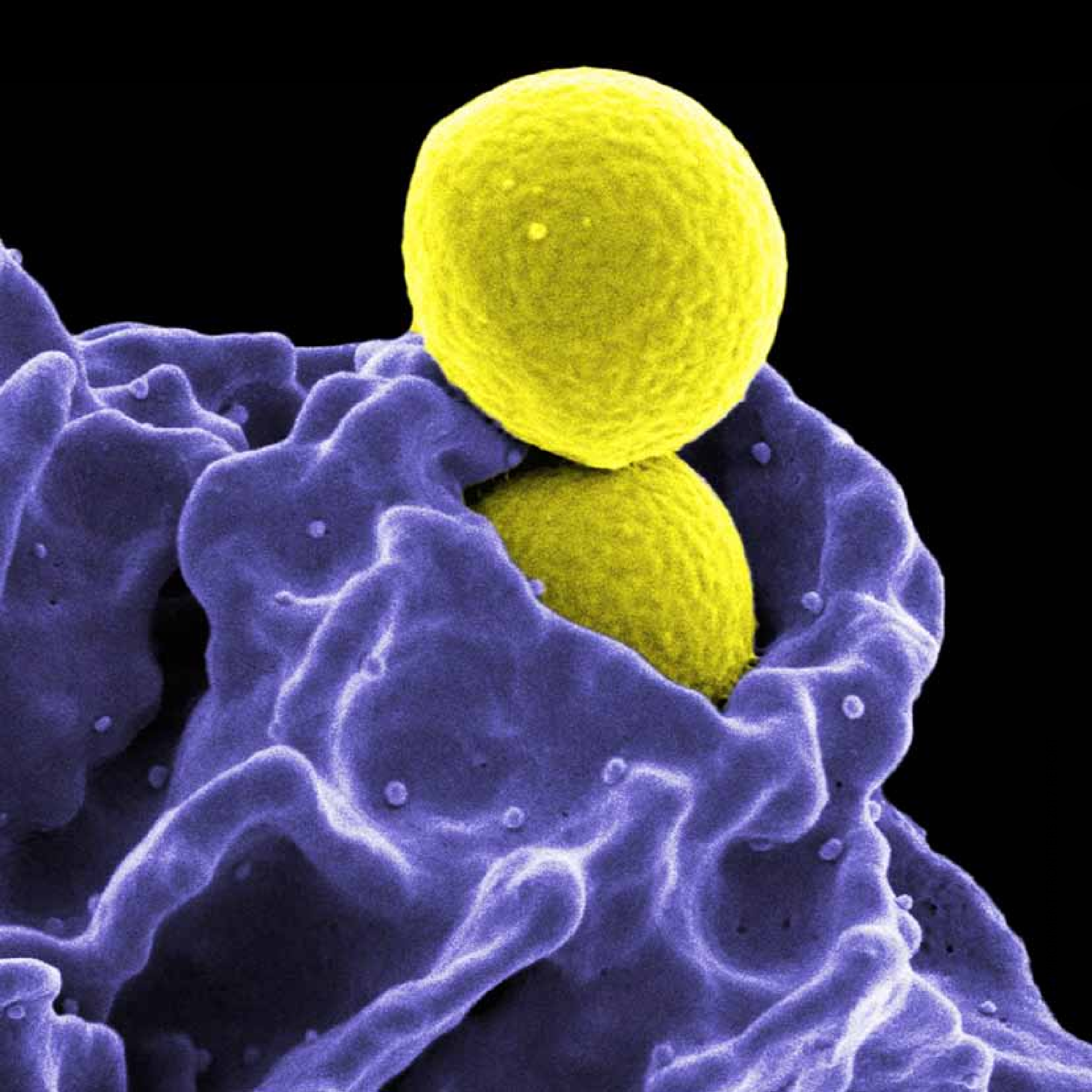
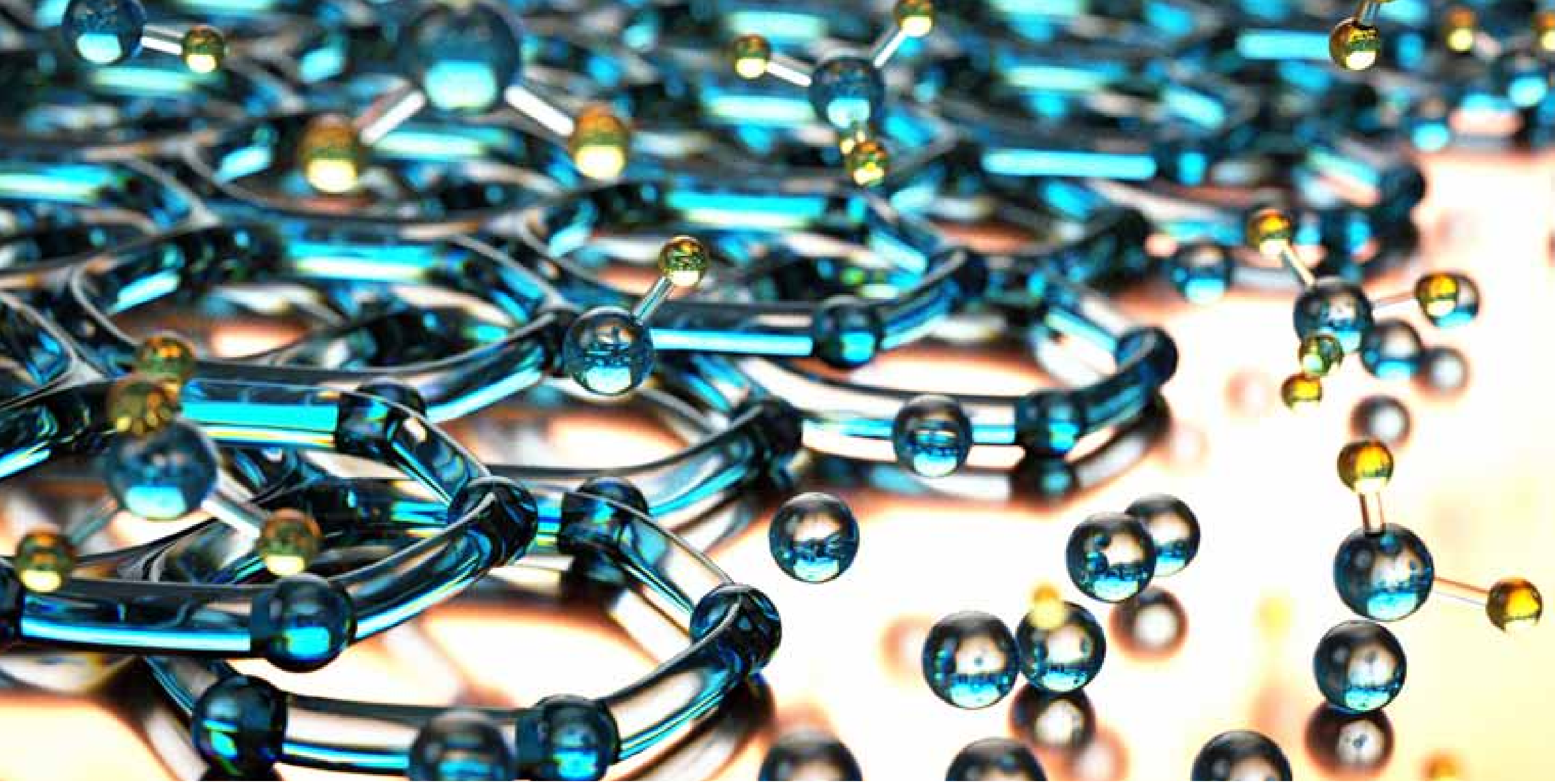
Methicillin-resistant Staphylococcus aureus bacteria being enveloped by a human white blood cell
Credit: US National Institute of Allergy and Infectious Diseases





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Nanomaterials: Applying the Precautionary Principle

Nanodimensions – New discoveries about familiar materials

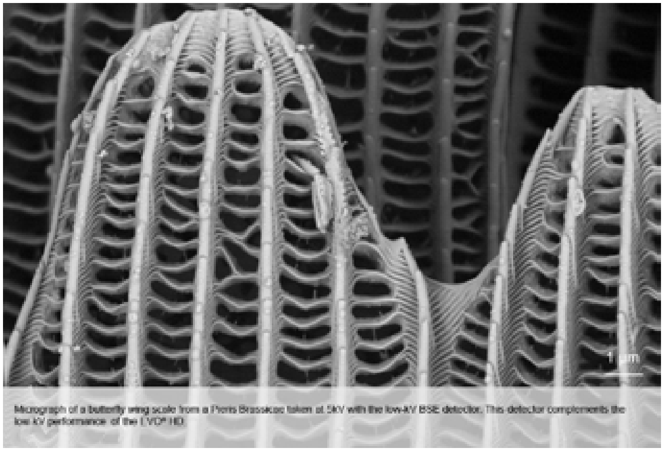
The 2016 Nobel Prize in Chemistry was awarded to Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa for their three decades of learning to design and synthesize molecular machines, demonstrated by a four-nanometre-long 'car' with four wheels operated by molecular motors.[1] Scientists have continued to push the boundaries and explore new technologies, in this case for innovations beyond physical limitations that realize the potential for countless applications in everyday life. The recent advances in nanotechnology and nanoscience have introduced nanoscale materials with emergent physical and chemical properties to transform the world.[2,3,4]

Nanomaterials are composed of nanosized particles, measuring less than 100 nanometres in at least one dimension: a nanometre is one-billionth of a metre, or roughly 80 000 times smaller than a human hair. Nanomaterials are not new and they are not all synthetic; they do occur naturally and they are everywhere. What is new is our ability to engineer them from common materials for a functional purpose.

In the natural world, nanomaterials appear in the skeletons of marine plankton and corals; bird beaks and feathers; animals' hair and bone matrix, including the human variety; spider webs; scales and wings; even in paper, silk and cotton. There are also naturally occurring inorganic nanomaterials, such as some clays, volcanic ash, soot, interstellar dust, and certain minerals. Natural nanomaterials are fundamentally a result of chemical, photochemical, mechanical, thermal and biological processes.[5,6]

Research suggests that some preparation methods used in traditional medicine, such as calcination, inadvertently produce nanomaterials and their particular attributes.[7,8] As well, researchers are examining medieval weapons, such as Damascus steel blades, to test the theory that specific and ritualized forging and annealing techniques exploited production of nanomaterials to enhance strength and suppleness of the steel.[9,10]

In the engineered world, nanomaterials are deliberately designed and synthesized for specific optical, electronic, mechanical, medical and enzymatic applications using a range of micro-fabrication techniques. Today, nanomaterials are widely used in a variety of products, such as food, cosmetics, personal care products, antimicrobial agents and disinfectants, clothing and electronic devices. Along with the excitement about opportunities the engineered nanomaterials could present, questions have emerged about the environmental safety of nanomaterials, as well as their production and applications. There are still significant gaps in our knowledge about what nanomaterials could do and what effects they might have. Despite many more nanomaterials being developed, there is a serious risk that we do not know enough about the long-term effects of these materials on human health or the environment to use them without greater safeguards in place.



Nanosized wing scale of Cabbage White Butterfly, *Pieris brassicae*

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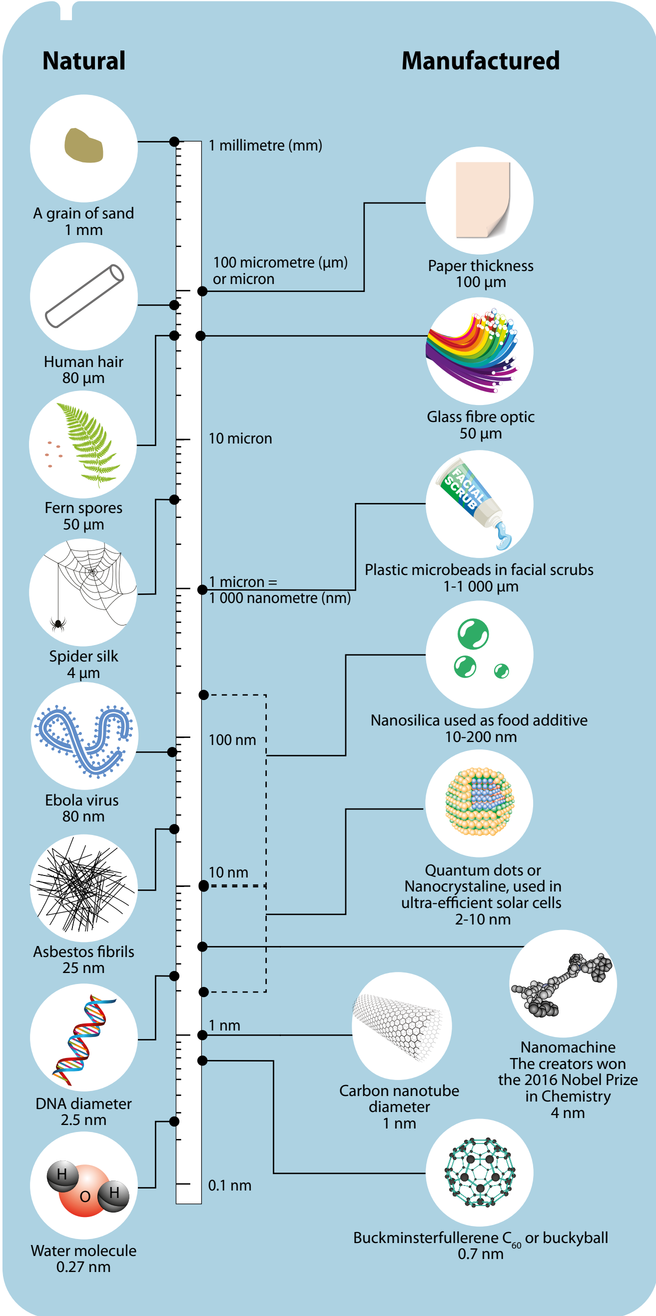
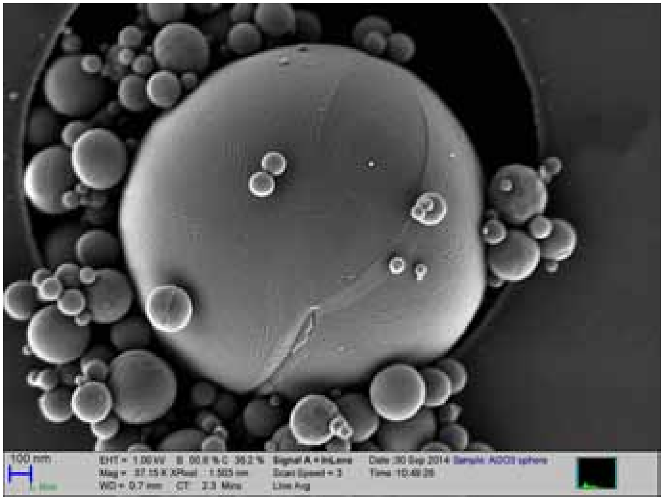


Specific forms, applications and effects

In Lewis Carroll's story of *Alice's Adventures in Wonderland*, young Alice swallows a potion that makes her very small. In her new size, she is able to enter a world of animals and characters that have extraordinary behaviours quite unlike their larger world versions. At nanoscale, the physical, chemical, optical, magnetic and electrical properties and behaviours of the materials change significantly compared to the same materials at larger sizes. This happens because of the dramatic increase in the surface-to-volume ratio and the appearance of quantum effects as a material gets smaller. Rendering a nanosized version of a material can produce capabilities in materials that are otherwise inert. For example, bulk gold is diamagnetic—it responds very weakly to magnetic field—but gold nanoparticles possess unusual magnetic properties.[11]

Like their bulk counterparts, nanoforms of metals, such as silver, titanium and zinc and their oxides, are used in sunscreen, toothpaste, cosmetics, food, paints, and clothing.[12] Due to its antimicrobial properties, nanosilver is widely incorporated into many consumer products such as sports textiles, shoes, deodorants, personal care items, washing powder and washing machines.



Aluminium oxide (Al_2O_3) nanospheres

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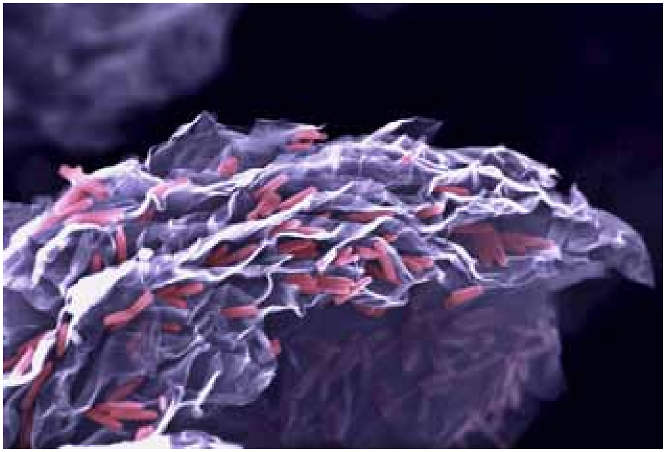


Iron (III) oxide (Fe_2O_3) nanorods, grown on reduced graphene oxide for supercapacitors

Photo credit: Dilek Ozg/Engineering at Cambridge, licensed under CC BY-NC-ND 2.0

Nanodiamonds demonstrate functional characteristics that enable them to penetrate through the blood-brain barrier, and allow targeted delivery of remedies to multiple types of cancerous tumours.[13,14] Because of their fluorescence, optical and electrochemical properties, nanodiamonds are used in advanced bioimaging techniques, and promising materials for transmitting signals that indicate the health of brain function.[15,16]

Nanozymes are nanomaterials with intrinsic enzyme-like properties developed for biosensing, bioimaging, tumour diagnosis and therapy.[17] They also find applications in marine anti-fouling, pollutant removal and environmental monitoring.

Carbon nanomaterials can present themselves in various shapes and forms. Graphene is a single-atom-thick sheet of carbon. Carbon nanotubes are essentially graphene sheets rolled into seamless hollow cylinders with diameters of the order of a nanometre.[18] Discovered in 1985, buckminsterfullerene, or buckyball, is a spherical structure of 60 carbon atoms, named after R. Buckminster Fuller, famous for his design of geodesic domes.

Nanomaterials

What is a Nanomaterial?

Nanomaterial is a material with any external dimension measured **less than 100 nanometres**—one nanometre is one-billionth of a metre

Cu Ag Ti Au Zn

Nanomaterials can be **naturally occurring**, or **fabricated** by scaling commonly used materials to nanosize, such as carbon, metal oxides and precious metals

Global Nanomaterials market

20.7% Annual Growth

Projected to reach **US$ 55 billion** by 2022

At nanoscale, the **properties and behaviours** of a material change significantly compared to the bulk forms of the same material. This is due to the increase in the **surface-to-volume ratio** and the **quantum effects**.

Bulk material — Nano-sized material

As material size decreases, surface area-to-volume ratio increases, making the material more chemically reactive to its surrounding environment

Applications

The unique **mechanical, magnetic, electrical** and **optical** properties of nanomaterials provide endless applications in pharmaceutical, biomedical, electronic and material engineering

Nanosilver is widespread in products, such as textiles, toys, personal and health care products, medical devices and food, owing to its **antimicrobial properties**

Engineered nanomaterials are present in **diverse consumer items**, e.g. food products, cosmetics, disinfectants, kitchenware, baby goods, clothing, fabrics, electronics and appliances

Because of its magnetic properties, **iron oxide nanoparticles** have great potentials for targeted drug delivery in cancer treatment, medical imaging techniques, and removal of arsenic from water

Nanodiamond is used in biomedical imaging applications due to its luminescent properties, high chemical stability and biocompatibility

Graphene is a single-atom-thick sheet of carbon atoms. Potential applications include drug delivery systems, molecular transporters, tissue engineering and implants.

A football-like cage of 60 carbon atoms, known as **Buckminsterfullerene** (C_{60}) or buckyball, has potentials for the treatment of bone and cartilage degeneration, and musculoskeletal and bone marrow disorders

Carbon nanotube is a one-atom thick layer of carbon rolled up into a seamless cylinder. It is 117 times stronger than steel of the same diameter and a better conductor than copper.

Carbon nanotubes are widely used in lithium ion batteries, lightweight wind turbine blades and data cables. Potential applications include tissue engineering and regeneration, and cancer biomarker.

Adverse Effects

Changing the properties of a material by nanosizing it can **intensify its health and environmental impacts**

The miniscule dimensions and high surface-to-volume ratio that give engineered nanomaterials remarkable properties also **alter how they interact** with and accumulate in biological systems, ranging from the environment, living organisms, organs, cells, down to the DNA level

For example, carbon nanotubes look and behave like asbestos fibres. Their long and pointy structure can pierce through tissue, and cause inflammation and fibrosis much like the effects of asbestos exposure. Nanosilver can disturb the immune system, and cause abnormality in gene expression

If we want to realise the full potential of engineered nanomaterials, we must also **anticipate their impacts**, otherwise we risk exposing ourselves to far greater impacts in the future

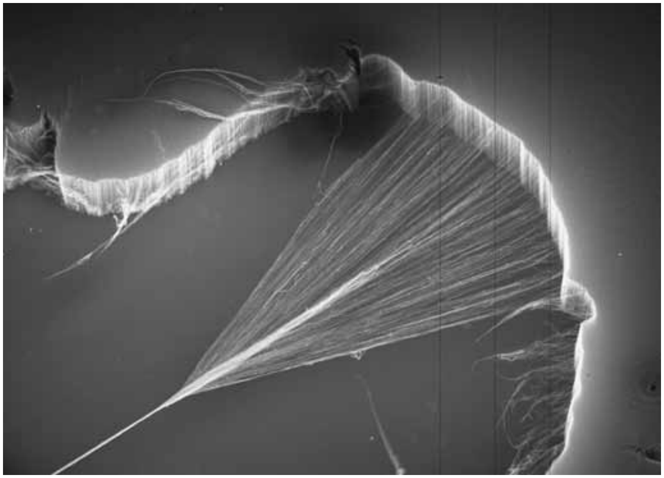
Iterative and responsive regulatory frameworks that **apply the precautionary principle** are needed to minimize the risks and ensure human health and environmental safety

Carbon nanotubes have amazing properties. They are stronger than steel, are better conductors than copper, and have higher thermal conductivity than diamonds. Carbon nanotubes are widely used in lithium ion batteries for notebook computers and mobile phones, lightweight wind turbine blades, boat hulls, data cables, and biosensors and medical devices.[19] The worldwide commercial production capacity of carbon nanotubes now exceeds several thousand tons per year.

As engineered nanomaterials replace more conventional materials in everyday products, it is vital that we know the adverse effects of such materials. If we want to realise the full potential of nanomaterials, we must also anticipate their environmental and human health impacts; otherwise we risk exposing ourselves to far greater risks in the future.[20]

Changing the properties of a material by nanosizing it can intensify its environmental and health impacts. In the case of nanosilver, its toxicity can cause argyria, which turns the skin permanently into a metallic blue colour; pulmonary inflammation; alterations in organ functions and disturbances to the immune system and gene expression.[12,21,22] Exposure to silver nanoparticles can produce a stress response and genomic changes in bacteria, which may contribute to the development of antimicrobial resistance genes.[12,23] Silicon and titanium dioxides can cause pulmonary inflammation.[24]

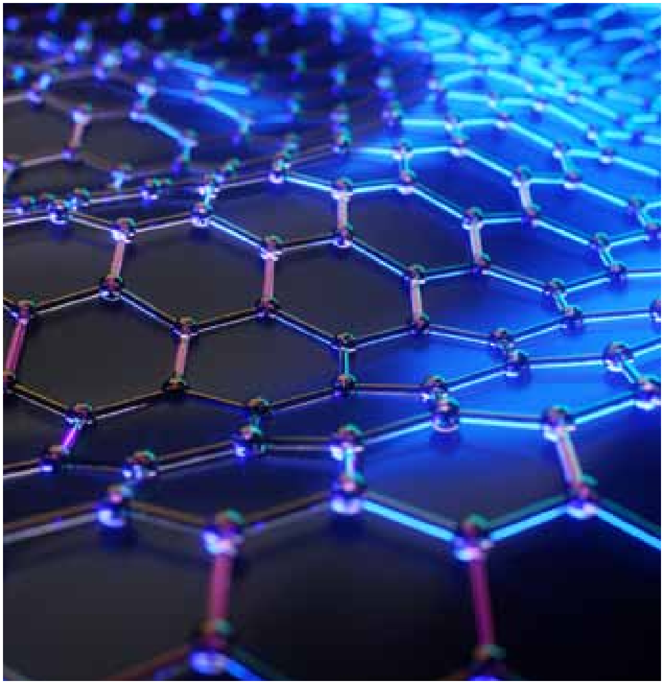
In parallel to the continuing discoveries of novel biomedical and therapeutic applications of fullerenes, including C_{60} buckyballs, these incredible nanomaterials are also under investigation for their potential effects on cells, gene expression, immune function, metabolism and fertility.[25] Carbon nanotubes and carbon nanofibres demonstrate their ability to cause damage to skin, eye, lung and brain tissues, and accumulate in the body.[26,27]



Carbon nanotubes being spun to form a yarn

Photo credit: Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Video: Graphene - the material of the future



Video link: https://www.youtube.com/watch?v=TFo2xShvtj0 *© DW Tomorrow Today*

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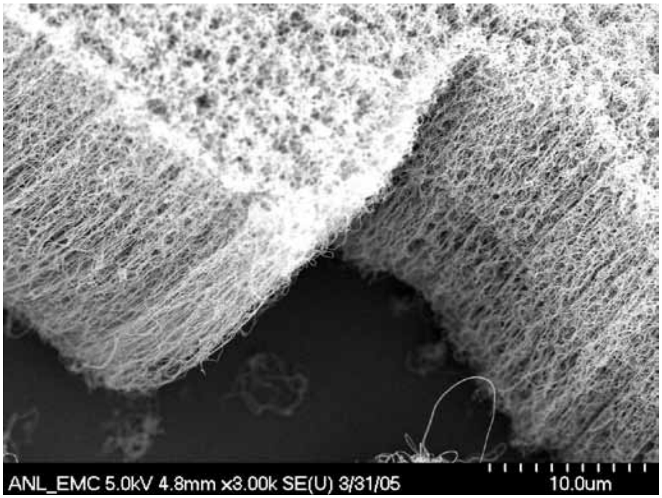
Environmental and health exposure to engineered nanomaterials

The global nanotechnology market is projected to grow roughly 18 per cent per year and be worth nearly US$174 billion by 2025.[28] The increased production and use of engineered nanomaterials by diverse industries will likely result in their unintentional release into the environment at any point along the product's lifecycle.[29] For example, nanosilver from clothing and fabric is released during washing; titanium dioxide nanoparticles in paint and building materials are emitted to the air and water due to weathering; and carbon nanotubes become airborne during production or leach from discarded lithium-ion batteries into soil and groundwater.[19,30,31]

To assess the potential human health and environmental risk, it is critical to understand the exposure and adverse effects of engineered nanomaterials.[32] At present, a limited number of studies are available to explain the fate of engineered nanomaterials once released into the atmosphere, soil, sediment, water and biota, including their behaviour, concentration, transport, distribution, transformations, bioavailability, bioaccumulation in food chains, and biochemical interactions with ecological communities.[29,33-36]

In contrast, knowledge and evidence of the toxicity effects of nanomaterials is expanding. Results suggest that nanomaterials can cause a wide range of adverse health effects. Comparative toxicity studies of familiar materials, particles and fibres with shape and chemical characteristics similar to those of nanomaterials, such as asbestos, ultra-fine particles and diesel exhaust fumes, provide insights into the potential health threats from being exposed to nanomaterials.[37] Further, what we have learned from managing these well-known hazardous substances could also help us to better prepare for the less understood nanomaterials.

Carbon nanotubes are found to share similar characteristics with asbestos fibres.[38] They have needle-like shape, and both are biopersistent. They can pierce through lung tissue and cause inflammation.[39] Evidence of the health hazard of working with asbestos came as early as 1898 from Lucy Deane, one of the first women Inspectors of Factories in the UK.[40] She noted that asbestos work was a 'demonstrated danger to the health of workers ... because of ascertained cases of injury to bronchial tubes and lungs medically attributed to the employment of the sufferer'.



Aligned carbon nanotubes

Photo credit: Junbing Yang/Argonne National Laboratory, licensed under CC BY-NC-SA 2.0

Asbestos fibres magnified 1500 times under scanning electron microscope

Photo credit: US Centers for Disease Control and Prevention/ John Wheeler/ Janice Haney Carr

Female workers lie on the asbestos mattresses they have produced at a Lancashire factory, United Kingdom, September 1918
Photo credit: © Imperial War Museum (Q 28250)

In 1982, a TV documentary, *Alice, a Fight for Life*, featured Alice Jefferson, a 47-year-old woman who contracted mesothelioma, a fatal form of cancer, from working for a few months at a local asbestos plant in the United Kingdom.[20] The story of this Alice had an immediate impact on British public opinion. The government responded by introducing asbestos licensing regulations that lowered asbestos exposure limits. A voluntary labelling scheme soon followed. Pressure continued to build, and so did scientific evidence on the mesothelioma epidemic due to past exposure to asbestos.[41]

It took until 1999 for all types of asbestos to be banned in the United Kingdom: 101 years after evidence of harm had begun to accumulate and thousands of people had died of asbestosis or related cancers. Today efforts are still made to minimize the risk of asbestos exposure to workers engaged in renovation and maintenance of buildings containing asbestos.[42]

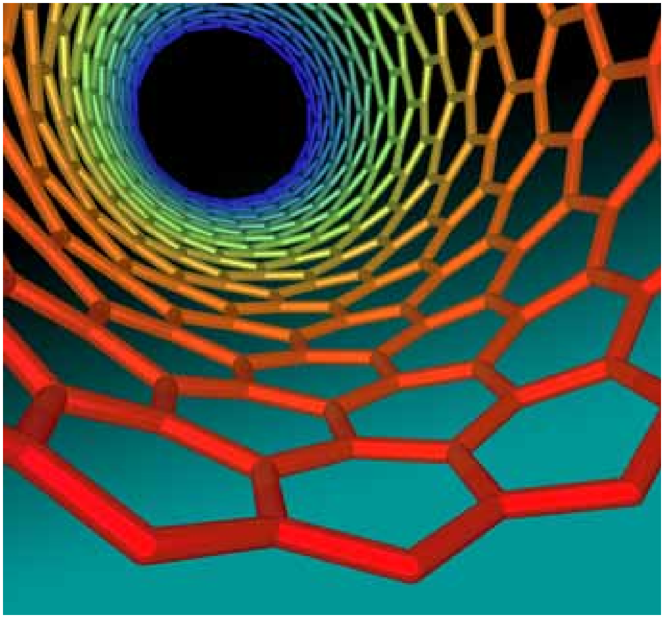
The question is, "What lessons can we learn from the century of struggle to understand and address the deadly dangers posed by exposure to asbestos when managing and assuring the safety of nanomaterials in the future?"

Appropriate regulations for health and environmental safety

From our experience with asbestos and other hazardous materials, we know the list of potential threats is long. Environmental exposure of engineered nanomaterials is inevitable. Their adverse effects and persistence could have significant consequences on organisms, ecosystems and food chains.[32,35,43,44] Oral, dermal and pulmonary exposure could lead to inflammation and fibrosis, disrupt metabolism and organ's function, and induce DNA damage and genetic instability.[22,26,45,46]

The speed of industrial development is far out-stripping the pace of regulatory development. In the absence of long-term monitoring and scientific information of the many aspects of nanomaterial toxicity and toxicology, specific regulations have been slow to emerge, despite mounting indications of potential exposure and risks.[47]

Video: Are carbon nanotubes the next asbestos?



Video link: https://www.youtube.com/watch?v=6L7xXgWcbrQ *© Museum of Life and Science*
Photo credit: Geoff Hutchison, licensed under CC BY 2.0

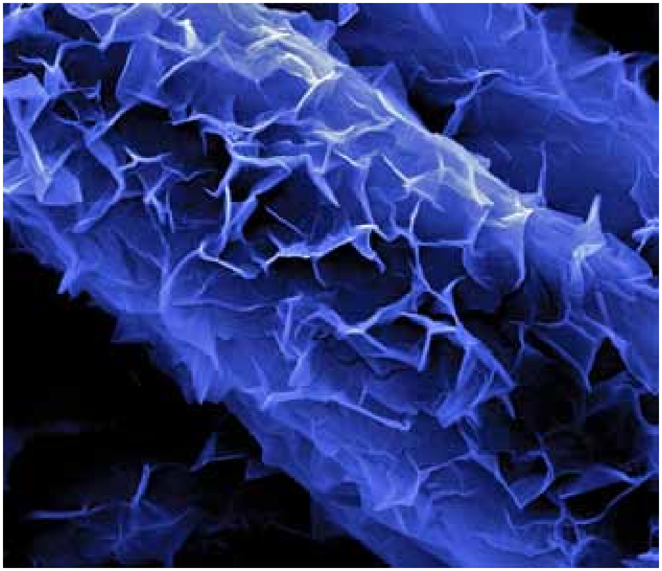
As in the case for asbestos, the first people exposed to nanomaterials are workers. The first few studies conducted in the late 1990s and early 2000s to assess occupational exposure to carbon nanotubes paved the way for further workplace investigations, and later the establishment of a first ISO-guideline on characterizing occupational nanoaerosol exposures in 2007.[48,49]

Based on studies of animals exposed to carbon nanotubes and carbon nanofibres, the US National Institute for Occupational Safety and Health considers findings such as lung inflammation, granulomas and fibrosis in subject animals to be significant enough to warrant action to set a recommended exposure limit.[22] The Organisation for Economic Co-operation and Development undertook multi-year programmes to generate toxicological data on a variety of nanomaterials to amend existing test guidelines for manufacturers.[50]

Because of the breadth of applications, regulatory bodies need to rely on existing regulations governing the areas of chemicals, pharmaceuticals, cosmetics, food, pollution, wastes and labelling to seek provisions for nanomaterials.[51] However, there are also challenges in applying existing regulatory frameworks to nanosized materials.[47] For instance, the reduction in size of a material may not initiate any need to revise the existing regulations or legislation if the nanosized and bulk materials are of the same chemical substance. Or, some consumer products are not subject to safety requirements and can enter the market without being tested.

In the European Union, the Regulation on Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) is used to ensure the human health and environmental safety of any chemical substance to be manufactured and marketed in the EU. Companies need to register the chemical substances they intend to manufacture and trade, and, based on REACH's specific guidelines, demonstrate how the risks associated with the substances can be managed for human health and environmental safety.[52,53]

At the global level, under the policy framework of the Strategic Approach to International Chemicals Management (SAICM) administered by UN Environment, nanomaterials



Carbon-graphene hierarchical core shell nanofibres
Photo credit: Ranjith Shanmugam/ ZEISS Microscopy, licensed under CC BY-NC-ND 2.0

are one of its emerging policy issues. It works with governments and international stakeholders to facilitate information exchange on nanotechnologies and engineered nanomaterials and to develop internationally applicable technical and legal guidance for the sound management of manufactured nanomaterials.[54]

When working with new technologies, regulatory bodies are confronted with a combination of promise, risk and uncertainty.[55] Expanding the research, production and use of engineered nanomaterials across the world will need transformative policies to encourage innovation and industrial applications of green chemistry, and more critically, iterative and responsive regulatory frameworks that apply the precautionary principle to assure safety and non-polluting outcomes. The world cannot afford to ignore the lessons of the past about risks and damages to human health and the environment when responding to the promising opportunities created by new materials.

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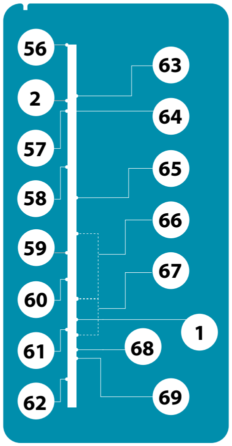
Graphic references



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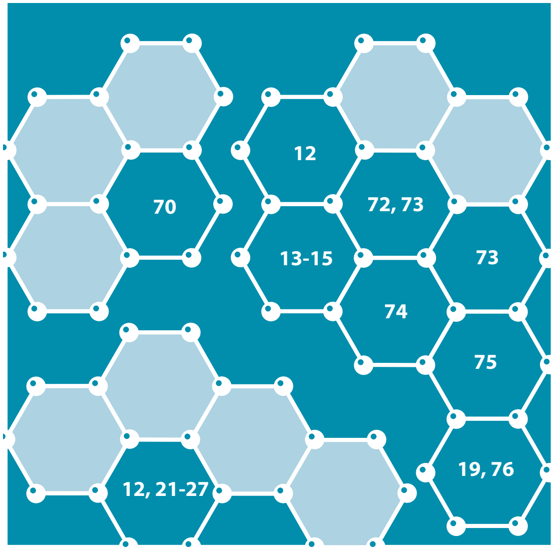

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Marine Protected Areas: Securing Benefits for Sustainable Development

Declining health for oceans: growing demand for their benefits

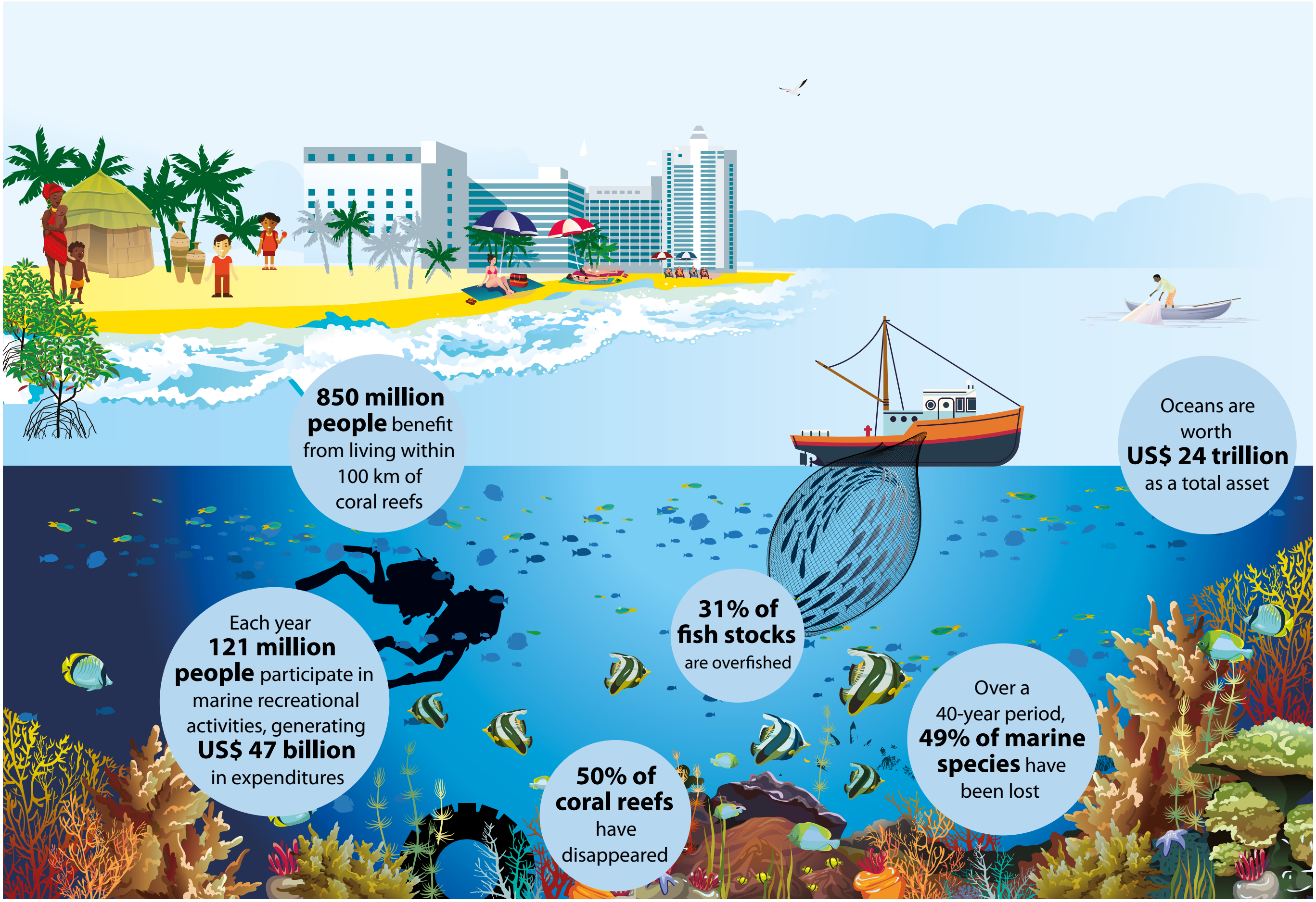
Our oceans have been under too much stress, from too many human activities, for too many years. Today, they face a complex mixture of environmental, social and economic impacts. Overfishing and other extractive activities, coastal development, pollution and tourism are damaging essential natural habitats and reducing populations of marine species at an incredible rate. This well-documented degradation is deteriorating further due to climate change, through the effects of warmer temperatures and the acidification that results when oceans absorb carbon dioxide from the atmosphere.

Since 1985, we have lost half of the world's coral reefs.[1] In 2016 alone, a 400-mile stretch of the Great Barrier Reef was severely damaged by coral bleaching.[2] Of the 600 fish stocks, or subpopulations, monitored by international research bodies, 31 per cent are currently fished at unsustainable levels, largely due to illegal, unreported or unregulated activities, and 58 per cent are fully exploited.[3] After a 49 per cent drop in fish stock populations between 1970 and 2012, a brief period of stability followed. Now, they are falling again.[4] In short, we are using the ocean's resources faster than ocean ecosystems can replenish them. It is a familiar destructive pattern: once we extract too many resources, weakened ecosystems recover more slowly. When we return for more, less of the resource is available and it is more difficult to extract. So, we put in more effort and cause more damage. Eventually, the resource is exhausted—or extinct.

This is a pattern of societal self-harm. Human life depends on the benefits oceans provide for health, well-being and economic growth. Ocean processes sustain the fish that provide the major source of protein for nearly three billion people.[3] A study shows that our oceans are worth at least US$24 trillion.[1] If oceans were a country, they would be equivalent to the seventh largest economy in the world.

Marine protected areas offer one of the best options for maintaining or returning ocean and coastal ecosystems to healthy conditions, particularly when developed as part of a wider management system.[5-10] Ecological benefits come from protecting species, habitats and ecosystem functions. Social benefits come from engaging stakeholders in the planning and the fair sharing of benefits. Economic benefits come from ensuring the long-term sustainable use of natural resources and tourism incomes. The combined impact could support many of the 17 Sustainable Development Goals of the 2030 Agenda for Sustainable Development, including reducing poverty, improving food security and tackling impacts of climate change.

Ocean and coastal values at stake



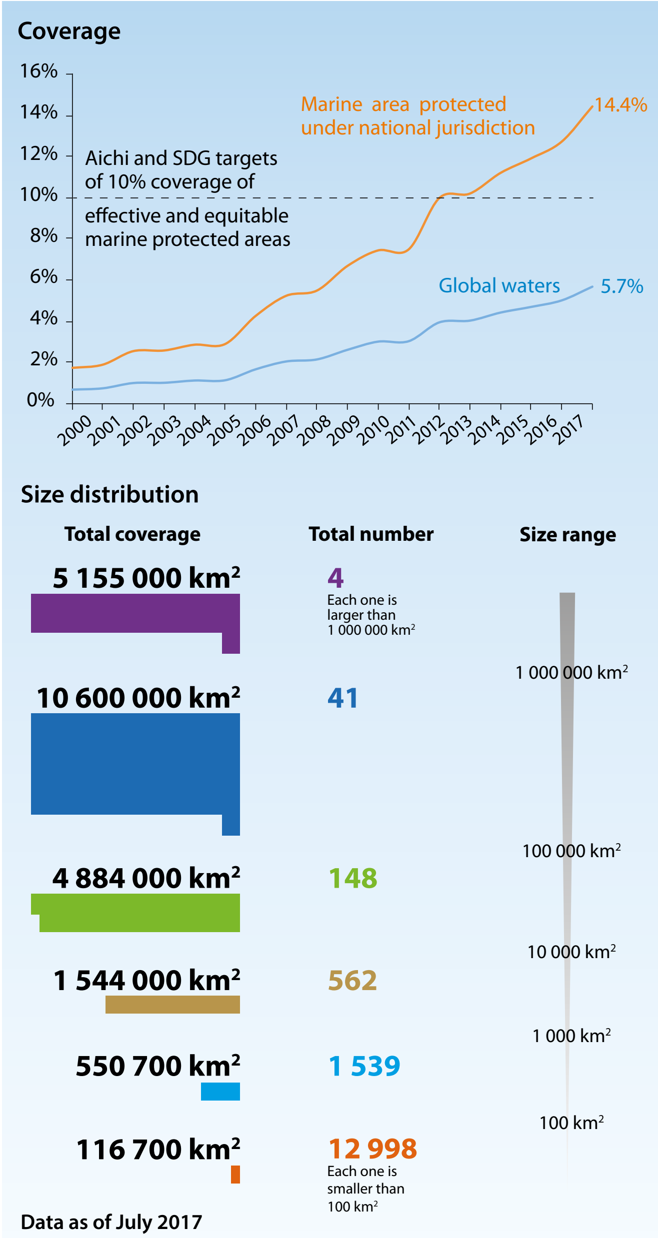
The rise of marine protected areas

Most countries now agree that we need to protect at least 10 per cent of coastal and marine areas by 2020.[11] This is one of the Aichi Biodiversity Targets and is echoed in the 2030 Agenda for Sustainable Development.[11,12]

Already, there has been a 25 per cent increase in the last 15 years.[13] By July 2017, 15 292 marine protected areas were designated, covering 5.7 per cent of the global ocean. Estimated 14.4 per cent of coastal and marine areas under national jurisdictions are designated as protected areas.[13] The latter number suggests that the 2020 target has been achieved for national seas, but the reality is a little more complex. It is complex because the physical area covered is just one part of the commitment. There are growing concerns that designation is not enough and the focus needs to shift to effectiveness.[14,15] There is some evidence that current governance capacity may not be sufficient to support effectiveness and delivery towards social and economic targets, as well those for biodiversity conservation.[16] Today, 45 of the 15 292 designated zones account for more than 72 per cent of the total protected marine area.[13] These large areas are important for maintaining secluded and pristine marine ecosystems. However, their size and remoteness also raises questions about the effectiveness of their governance strategies and the limited opportunity to share the benefits.[14] Marine protected areas must provide effective biodiversity conservation and the *equitable* sharing of related costs and benefits. The emphasis should be on both quality and quantity.

The questions on effectiveness are not limited to very large marine protected areas. A new UN Environment study, "Enabling Effective and Equitable Marine Protected Areas: Guidance on combining governance approaches", has analysed the governance of 34 protected areas in national seas.[16] Just over half were given a medium effectiveness rating, indicating that some human impacts are completely addressed and others partially. The remainder were given a low effectiveness rating, indicating that some impacts are addressed either inadequately or not at all. Additional studies show that about 40 per cent of marine protected areas have major deficiencies, leading to weak and ineffective governance.[17]

Recent trend in global coverage of marine protected areas



Data source: UN Environment World Conservation Monitoring Centre

Better governance makes marine protected areas more effective

For marine protected areas to be truly effective they need strong governance to influence human behaviour and reduce the impacts on the ecosystem. The approach should be inclusive, promoting a sense of stewardship that demonstrates the social, economic and environmental benefits for user communities.

Because our seas are intricate ecological systems that support complex social and economic systems, maximising the effectiveness of protected areas can be resource intensive. Often challenges include lack of knowledge, political will, community support and financial investment. Too often, marine protected areas are seen as a short-term up-front cost, rather than being embraced as long-term investments with substantial social, economic and environmental benefits. Each MPA has different challenges, but marine resource users are less likely to flout rules and regulations if they are involved in discussions and decision making.

Marine protection debates ask about the best or correct way to improve governance, focusing on three approaches. Each of them has drawbacks: Top-down governance focuses on regulations imposed by governments. This can lack the inclusion of local communities, causing less collaboration. Bottom-up governance focuses on locally agreed restrictions with which people cooperate. This can lack the legal enforcement to restrict incoming users. Market-based governance focuses on economic initiatives producing financial gains, such as giving local communities alternative livelihoods and property rights. This approach can impede conservation objectives by disrupting local cooperation and creating additional environmental damage.

Research on the effectiveness of marine protected areas shows that focusing on a single governance approach creates weaknesses that can compromise conservation intentions. Instead, there should be an integrated approach that combines the roles of national governments, local communities, and market schemes.[16,18] The relative importance of each role will depend on the behaviour to be addressed and the wider environmental, social, economic and political context.

Aichi Biodiversity Target 11

By 2020, at least 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures and integrated into the wilder seascape

SUSTAINABLE DEVELOPMENT GOALS

14 LIFE BELOW WATER

Target 14.2

By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration

Target 14.5

By 2020, conserve at least 10 per cent of coastal and marine areas, consistent with national and international law and based on best available scientific information

Video: How to choose marine reserves

Video Link: https://www.openchannels.org/videos/how-choose-marine-reserves
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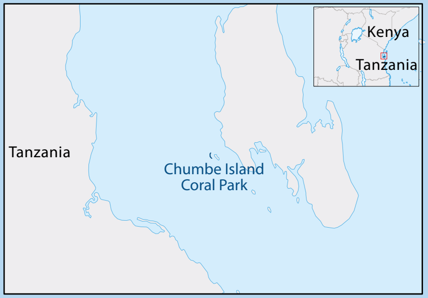
Combining governance approaches in practice

Chumbe Island, Tanzania



Private marine protected area:

- Mainly funded by eco-tourism initiatives
- High staff to tourist ratio to create more jobs, 95% of staff are Tanzanian
- Strong collaboration with Tanzania's Department of Fisheries to enforce penalties, supported by local wardens, fishermen and police

Bluefields Bay, Jamaica

Community-led marine protected area:

- Discussions and decisions involve all relevant local communities
- Aiming for financial independence to support itself and the local community
- Government funds patrols to enforce regulations, which are supported by state laws
- International and local organisations handle financial and operational management, provides skilled resources for training and education

Great Barrier Reef Marine Park, Australia

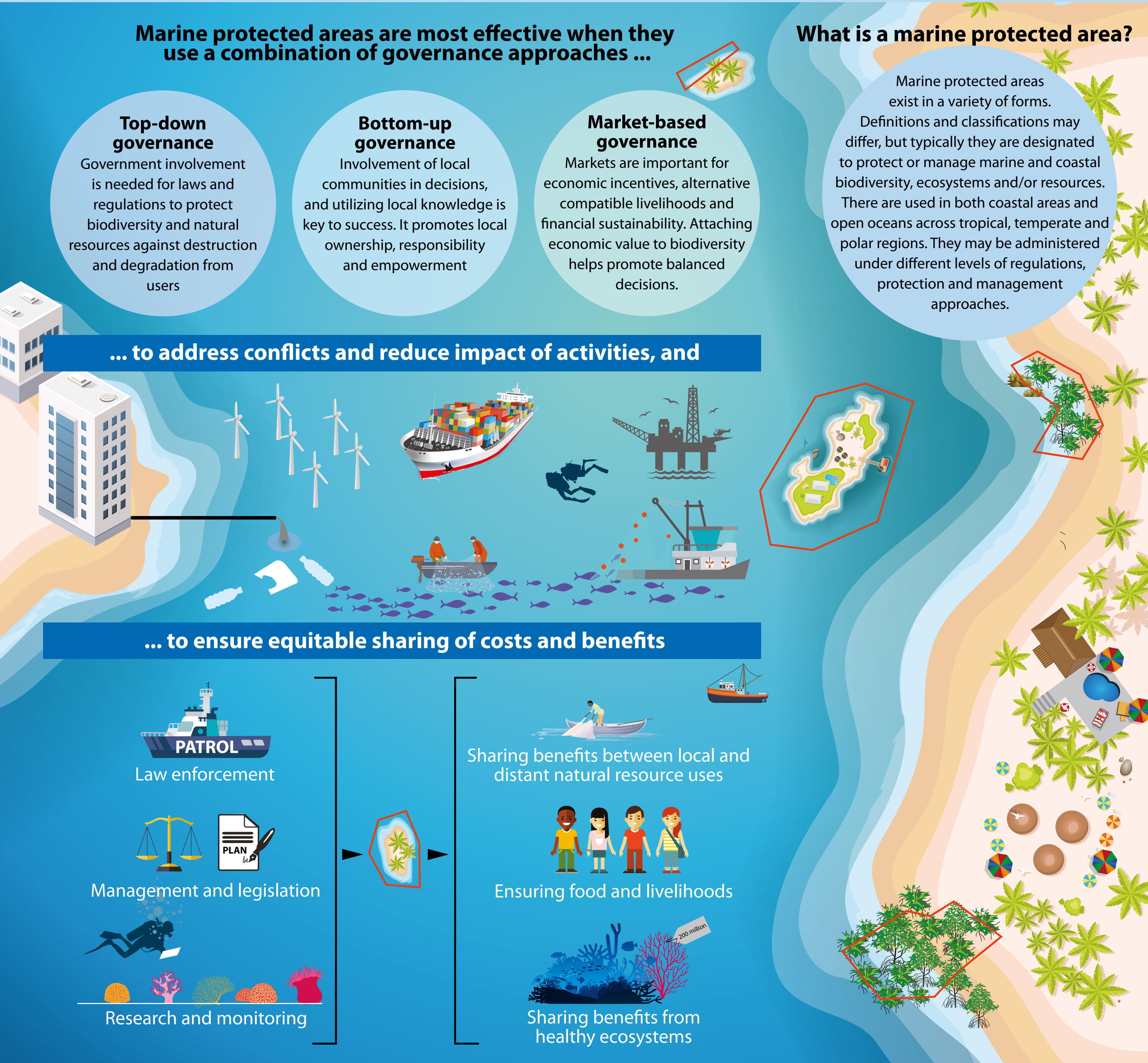
Multiple-use protected area:

- Close collaboration between federal and state governments
- Zoning system for equitable sharing of benefits from ecosystem services
- Tourism employs over 70 000 people and generates income of AUD5 billion each year
- Collaboration with indigenous communities to ensure livelihoods, culture and traditions, for example fishing rights are protected

Every protected area is unique, but there are common driving forces that can increase governance challenges. These forces include expanding demands from global fish markets that drive up the levels of commercial fishing; local poverty that drives people to fish for subsistence and basic livelihoods; growing tourism that increases pressure on infrastructure development and recreational access; and economic migration from poorer inland areas to coastal areas seeking opportunities for work or a better standard of living.[16,18] These forces could undermine conservation objectives. Clearly, defining the objectives during the marine protected area designation process makes it possible to understand the specific requirements for addressing conflicts and supporting the effectiveness of the protected area. A governance framework can support the development and implementation of measures to mitigate specific human behaviours and should include enforcement and financial strategies to support the overall objectives of the protected area. At the same time, it should allow benefits and costs to be equitably shared, while still protecting biodiversity.

Case studies of marine protected areas demonstrate how combinations of governance approaches can be effective. Australia's Great Barrier Reef Marine Park is an example of a top-down effort, while collaboration with local indigenous communities ensures their livelihoods, cultures and traditions; Tanzania's Chumbe Island Coral Park is a private, ecotourism-focused protected area, while there is strong collaboration with the government to enforce penalties, supported by local wardens, fishermen and police; and Jamaica's Bluefields Bay is a community-led conservation area, but the government funds patrols to enforce regulations supported by state laws. Each of these efforts has adopted techniques from various approaches to adapt to local needs and conditions.[16,18]

Governance of marine protected areas



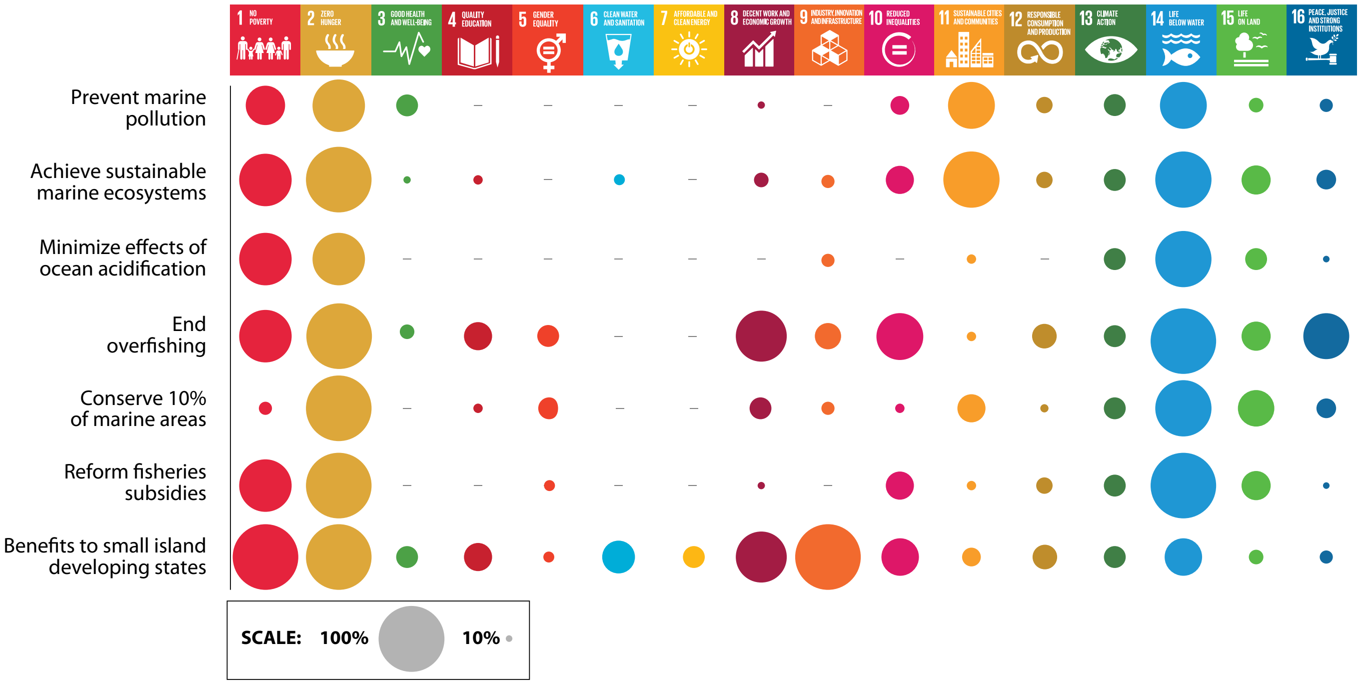
The future: using protected areas for sustainable development

The opportunities created by marine protection are as vast as the ocean. However, a perception shift is required to focus on the quality as well as quantity of protected areas, and to recognise the benefits as well as the costs. Economic and social benefits can comfortably co-exist with marine protection, if governed with a full understanding of the surrounding environment.

An economic scenario estimates that a network of protected areas covering 10–30 per cent of our oceans could cost US$45–228 billion, but could deliver astonishing social and economic gains through the provision of ecosystem service benefits (for coastal protection, fisheries, tourism, recreation and carbon storage) of US$622–1 145 billion over the period 2015-2050.[19] Such benefits could be between 3 and 20 times greater than the costs. That could also mean more productive and sustainable fisheries and a reduction in the decline in global fish stocks. There would be a growth in tourism and other economic opportunities.[20] For example, studies suggest that increased biodiversity from a protected area can attract up to 36 times more revenue from tourism than from fishing.[21] In addition, cost-benefit analysis suggests there are economies of scale to be achieved from increasing the size of marine protected areas in relation to establishment and operational costs.[19]

However, as with broader marine governance, there is no single solution. Each scenario must be individually considered. As noted earlier, there are indications that larger marine protected areas can have lower levels of management and effectiveness.[15,17,18] Diminishing returns have also been suggested as scale increases, but this depends on the volume of biodiversity in each area.[19] Each site would require

Co-benefits of achieving targets for Sustainable Development Goal 14: Life below water



Source: Adapted from Singh et al. (2017)[22]

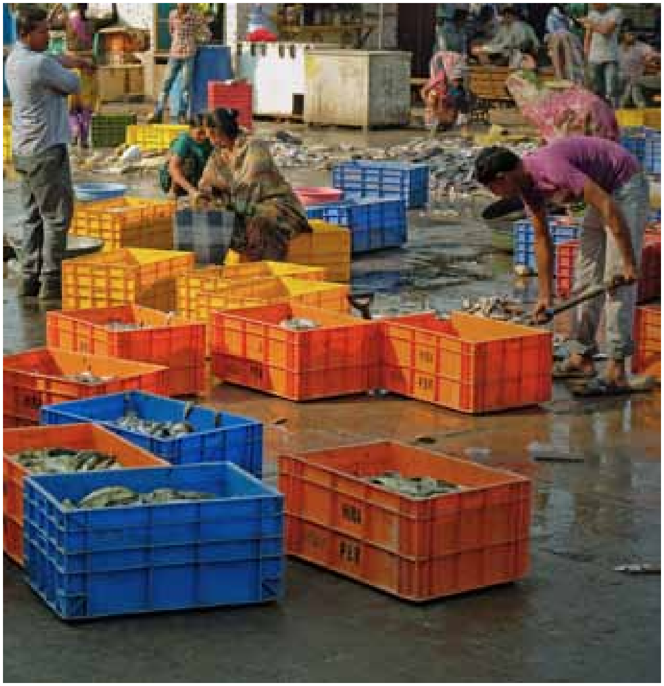
a cost-benefit analysis to understand the social, economic and environmental implications. They would all have to demonstrate their effectiveness at reducing impact on marine resources and ecosystems, while increasing the equitable sharing of benefits.

In 2016, the Rome Call to Action and the related Scientists' Consensus Statement set out a road map to promote effective and equitable marine protected area with clear targets and actions.[23,24] The United Nations Oceans Conference, June 2017, built on this, recognising the need to combine biodiversity conservation and sustainable use, with a clear role for people and the equitable sharing of costs and benefits.[25]

Efforts to ensure healthy oceans and coasts may present a good return on investment in terms of delivering wider sustainable development. A recent study highlights many co-benefits from achieving the different targets under Sustainable Development Goal 14 on oceans towards the attainment of the overall 2030 Agenda for Sustainable Development.[22]

This is the important opportunity to strengthen our efforts to safeguard the health of our oceans and thereby continue to benefit from them. It is more vital than ever for countries to look beyond achieving maximum coverage targets for marine protected areas, to be able to use them to achieve sustainable development.

Video: Fisheries Economics & Policy: Marine protected areas



Video Link: www.youtube.com/watch?v=n6_JLZnQe6Y
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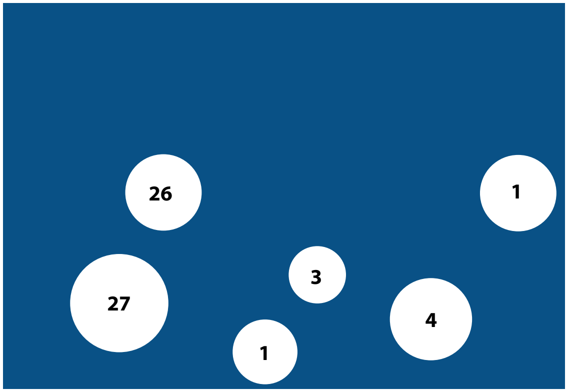
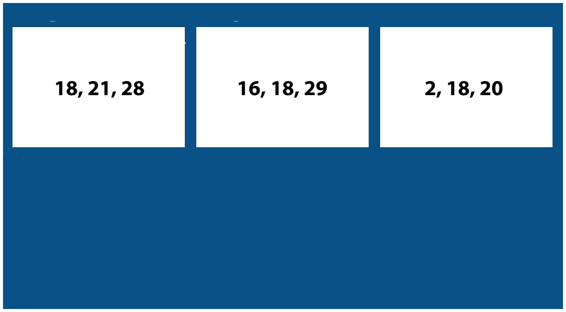




A sandstorm hovering over the African Union-United Nations Mission in North Darfur, El Fasher, Sudan
Photo credit: UNAMID/Adrian Dragnea

Sand and Dust Storms: Subduing a Global Phenomenon

Invasion by sand and dust

In 2010, Chinese authorities issued a level-five pollution warning as a massive sandstorm moved from Mongolia and northern China towards Beijing, hovering over an area of 810 000 square kilometres and threatening 250 million people.[1] In May 2016, a series of massive sand storms swept across Rigan County in southeast Iran, burying 16 villages and causing USD 9 million in losses.[2] A few months later, heavy dust and sand clouds engulfed Abu Dhabi, reducing the visibility in the city to 500 metres and increasing the number of asthma patients admitted to hospitals by 20 per cent.[3,4] These are just a few examples of recent threats and damages that sand and dust storms delivered to many parts of the world. Other examples abound throughout human history.[5]

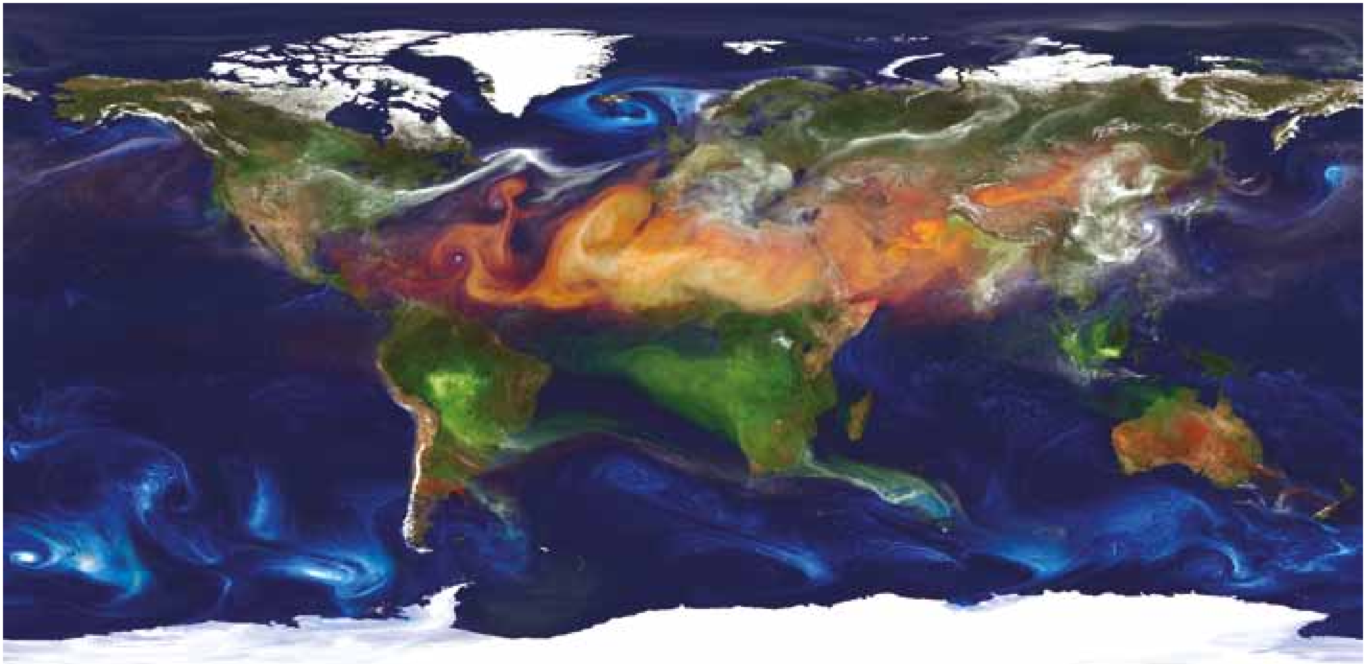
Sand and dust storms result when strong turbulent winds erode sand and silt particles from arid and semi-arid landscapes and then launch them into the air. Sand storms move relatively close to the ground and both particle size and wind speed constrain the distance each particle travels. Dust storms raise large quantities of fine silt particles and smaller clay particles higher into the atmosphere.[6]

Dust storms can travel thousands of kilometres across continents and oceans, entraining other pollutants on the way and depositing particles far from their origin. Winds spread the dust of the Sahara—the most significant source—west to the Americas, north to Europe and east to China.[6] Central Asian and Chinese sources reach the Korea peninsula, Japan, the Pacific Islands, North America and beyond.

A 2003 case study traced large amounts of dust from a 1990 Chinese plume that reached the European Alps—travelling eastward more than 20 000 kilometres within two weeks.[7] Dust plays an important role in biogeochemical processes throughout the Earth system. It forms a source material for vast expanses of loess soils.[8] Mineral dust deposition provides nutrients such as iron and other trace elements to terrestrial and marine ecosystems, boosting primary productivity and phytoplankton growth.[9] Saharan dust is a natural fertilizer of the Amazon rainforest, providing phosphorus inputs that balance losses through river discharge.[10] Similarly, Hawaiian rain forests receive nutrients from the dust of Central Asia.[11] At the same time, dust from Africa and Asia may damage Caribbean coral reefs.[12]

Dust can also harm animals and humans, especially in arid and semi-arid regions. For humans, inhaling fine particles can generate and aggravate asthma, bronchitis, emphysema, and silicosis.[13] Finer dust also can also deliver a range of pollutants, spores, bacteria, fungi and allergens. Other common problems include eye infections, skin irritations and Valley Fever. In countries of the Sahel, dust loads arriving from the Sahara correlate strongly with meningitis outbreaks.[14] Chronic exposure to fine dust contributes to premature death from respiratory and cardiovascular diseases, lung cancer and acute lower respiratory infections.[15]

Other socioeconomic damages follow dust storms.[16-19] Short-term costs include disease and death in livestock, crop destruction, damage to buildings and other infrastructure, transport shutdowns and expensive removal of tonnes of deposits. Economic losses from a single storm event can be hundreds of millions of dollars. Longer-term costs include erosion of soils, pollution of ecosystems, chronic debilitating health problems, and desertification.



A portrait of global aerosols produced by a GEOS-5 simulation at a 10-kilometre resolution. Dust emission can be seen in brown/red colour.
Photo credit: William Putman, NASA/Goddard Space Flight Center

Drivers from nature, land mismanagement, and climate change

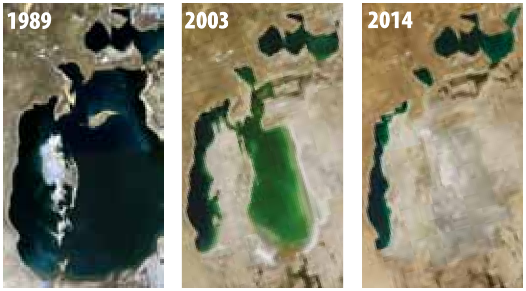
Dust activities vary significantly on a variety of time scales, such as seasonal, annual, decadal or multi-decadal scales.[20] A 2012 study of satellite data from 2003 to 2009 in comparison with similar analyses of data from earlier periods suggests that over the past three decades, substantial changes have occurred in Australia, Central Asia and the US high plains; whereas dust events over Northern Africa, the Middle East and South America have remained at the same level of activity.[21,22] Further studies show that these regions experience frequent high dust intensity as storms or haze events derived from both natural and anthropogenic causes.[21-23]

The anthropogenic causes, responsible for about 25 per cent of global dust emission, result from land use changes that include excessive water extraction and water diversion for irrigation, leading to drying out of water bodies; and deforestation and unsustainable agricultural practices, which expose soils to wind erosion. These are all forms of land degradation. In drylands, when agricultural soils are tilled too often and too deeply and crop residues are removed, soils are left exposed. Removal of hedges and windrows to allow for larger equipment increases wind erosion. Overgrazing of rangelands results in loss of soil cover. When the soils have no ground cover, winds lift away the finer particles containing much of the soil's nutrients and organic matter. Model simulations suggest that globally, dust emissions have increased between 25 to 50 per cent due to a combination of land use and climate change since 1900.[24]

In every dust-prone region, the relationship between human activities and increased dust is visible and sometimes palpable. The Owens (dry) Lake dust source in California was desiccated after water diversions to the Los Angeles Aqueduct began in 1913.[25] Patagonia in the southern half of Argentina has become a major anthropogenic dust source from desertification caused by unsustainable ranching.[26] The Indo-Gangetic basin is a principal dust source in South Asia, resulting from intensive agricultural activities.[22] In Australia, land clearing and water demand for agriculture has disrupted the hydrological regime and led to significant increase in dust.[27] Lake Balkhash in Kazakhstan has been rapidly drying since 1970 after completion of a dam upstream on the Ili River.

Shrinking Aral Sea from 2000 to 2013

Following decades of large-scale water diversion, the Aral Sea has dried up and become active sources of dust



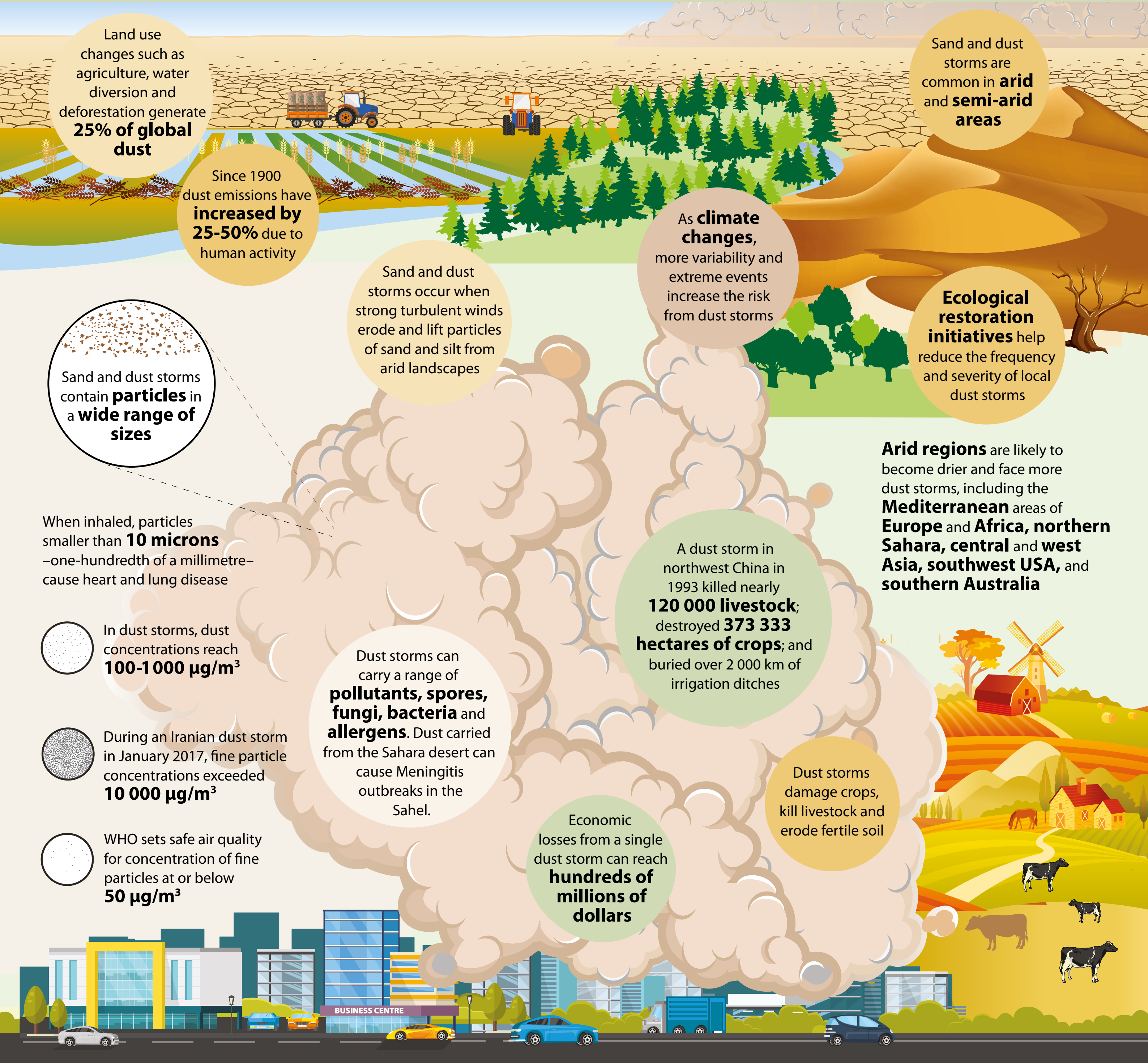
Credits
1989 - University of Maryland Global Land Cover Facility
2003 - Jacques Descloitres, NASA/Goddard Space Flight Center
2014 - Jesse Allen, NASA Earth Observatory

And finally, decades of large-scale diversions–from the region's main rivers, the Syr Darya and Amu Darya, to extensive irrigation schemes–reduced river flow reaching the Aral Sea, with consequent desiccation and desertification throughout the region.[28] Vast areas of the Aral Sea Basin are now active sources of noxious dust polluted with the persistent residue of artificial fertilizers and pesticides that were banned from use decades ago.[29]

Anthropogenic climate change is an important driver of dust generation, in addition to that produced naturally and by unwise land management. Many regions that are currently dusty areas will likely become drier and contribute more atmospheric dust. These include most of the Mediterranean areas of Africa and Europe, northern Sahara, West Asia, Central Asia, southwest USA, and southern Australia.[30,31] In turn, increased dust in the atmosphere can influence the climate system. It can disturb the earth's radiative balance, intensifying droughts in arid areas.[32] On the other hand, dust could enhance precipitation in some areas, by seeding clouds.[33]

Sand and dust storms are thus inter-connected with a range of environmental and development issues that extend across national, regional, and continental bounds. Anthropogenic climate change will further exacerbate decades of unsustainable land and water resource management in regions that generate sand and dust storms. This threat can be diminished by quick and effective action.

Sources and impacts of sand and dust storms



Reducing damage through focus on smaller scales

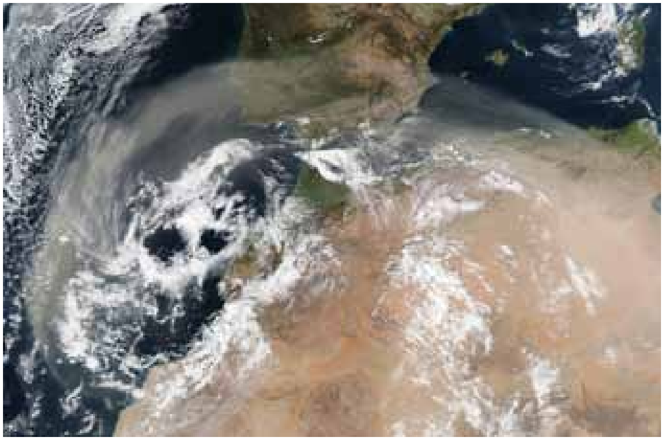
In the short to medium-term, successful efforts to reduce threats from sand and dust storms should focus on protective strategies.[34] Of course, early warning systems and disaster reduction procedures are essential components of preparedness, and regional programmes are evolving to refine these services. Procedures for coping in real time with sand and dust storms include advisory communications to public services; school, airport, rail and road closures; and hospital emergency services.

Preparedness starts with public awareness of sand and dust storm risks through education in schools, media and social networks and telecommunication. Preparedness should also include techniques that provide physical protection of valuable assets such as planting or erecting barriers upwind of populated areas and essential infrastructure to encourage dust deposition outside those areas. Some actions, such as aligning roads and removing traps, channel dominant winds and their burden away from sites needing protection.

In the medium to long-term, reducing the threat from sand and dust storms should focus on preventive strategies

Video: Africa's ambitious "Great Green Wall"

Video Link: https://www.youtube.com/watch?v=jl_nRHg-0l4 *© TIME*
Photo Credit: Tilling soil in Senegal by IFPRI/Milo Mitchell, licensed under CC BY-NC-ND 2.0

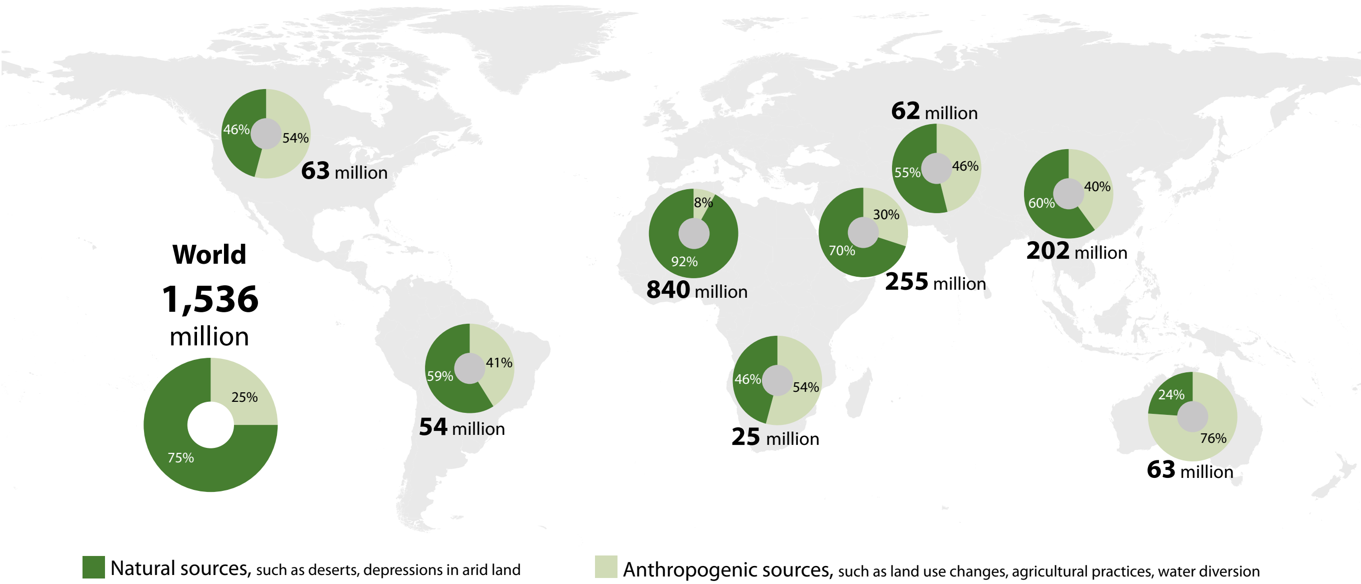


A dust plume blowing from Northern Africa towards Europe and the Atlantic Ocean, 21 February 2017
Photo credit: NASA image by Jeff Schmaltz, LANCE/EOSDIS Rapid Response

that promote sustainable land and water management across landscapes. This level of scope addresses cropland, rangelands, deserts, and urban areas. Such strategies should integrate with measures for climate change adaptation and mitigation, as well as for conserving biological diversity. These crucial integrated strategies are currently deficient in many vulnerable regions.[34]

The Three North Shelterbelt Program in China, sometimes called the Green Great Wall, is an integrated effort that began in 1978 to address rampant soil erosion, which exacerbated existing problems with flooding and dust storms over large expanses, after decades of unsustainable natural resource exploitation. Research results and lessons learned suggest that a focus on what works at community and local levels, with local plant species already adapted to specific locations, brings success when linked and scaled up.[35] These insights renew emphasis on actions that promote ecosystem services such as food production, carbon sequestration, soil and water retention, flood mitigation, and provision of habitat for biodiversity conserving natural capital, as well as prevention of sand and dust storms.[36] Observations on Green Great Wall efforts show significant improvements in the surrounding vegetation index and deduce these efforts have effectively reduced dust storm intensity, after accounting for influences from climatic change and human pressures.[37,38]

Sources of dust emissions (tonnes/year)



Data source: Ginoux et al. (2012)[22]

In the Kubuqi desert of Inner Mongolia, private-public-community investments to plant local species of trees, shrubs and grasses on more than 5 000 square kilometres of desert land reduced the frequency of dust storms and the amount of related damage to homes and infrastructure.[39]

In Africa, the Great Green Wall for the Sahara and the Sahel Initiative is also finding success by working at local and community scales.[40] The initiative has graduated from a tree planting vision to focus on broader sustainable development: In Senegal they started by planting more than 270 square kilometres of indigenous trees that do not need watering. Later, other plants and animals are reappearing to restore the ecosystem. Communities in Mauritania, Chad, Niger, Ethiopia and Nigeria are growing market gardens along the dryland edge giving the young population work and reasons to reject migration. Once again, to succeed these projects carefully select plant species that are well adapted to local conditions, matched to water resource availability, and familiar to local residents who will ultimately be responsible for maintaining the restoration and the landscape.[41]

Economic losses due to sand and dust storms

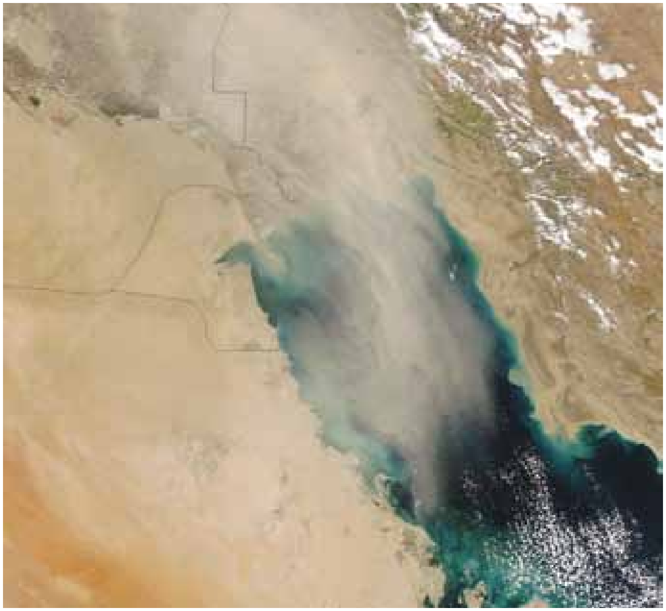
Multilateral support for reducing sand and dust storm damage

Integrated strategies that address sand and dust storm threats reflect recommended actions to contain land degradation, terrestrial biodiversity loss, and climate change threats under the three Rio Conventions: the UN Convention to Combat Desertification (UNCCD), the UN Convention on Biological Diversity and the UN Framework Convention on Climate Change, respectively. Supported by the UNCCD, West Asia and Northeast Asia have developed Regional Action Plans on sand and dust storms and the Northeast Asia plan is in full operation.[42]

Each Rio Convention supports land and water management efforts in partnership with appropriate multilateral institutions and agencies. International unity on these issues is reflected in the Sustainable Development Goals–particularly Goal 1, 2, 5, 13 and 15–that address the integrity and management of land and water resources, and specifically Target 15.3: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world."

Video: Combatting desertification: Chinese herdsmen dedicated to turn desert into oasis

Video Link: https://www.youtube.com/watch?v=giTXPUrYYJ0 *© CCTV English*
Photo credit: Preventing desertification in Ningxia, China by Bert van Dijk, licensed under CC BY-NC-SA 2.0



A dust storm over the Persian Gulf, 19 February 2017
Photo credit: NASA image by Jeff Schmaltz, LANCE/EOSDIS Rapid Response

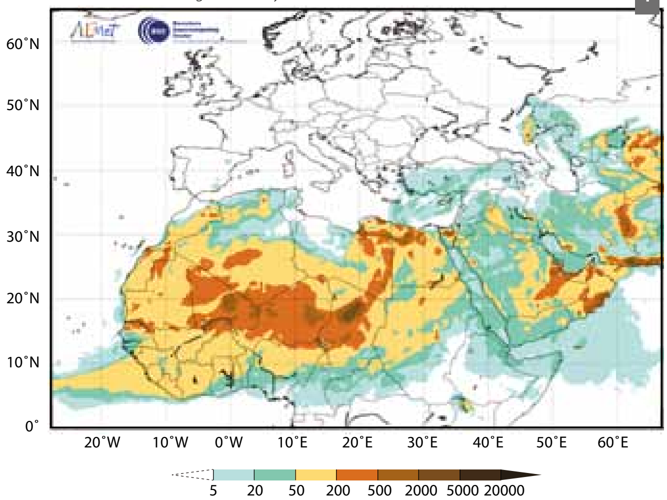
Regional frameworks, agreements and action plans such as the Regional Master Plan for the Prevention and Control of Dust and Sand Storms in Northeast Asia and national action plans, such as those required by the UNCCD, also establish policies for reducing sand and dust storm threats.

The World Meteorological Organization has established the Sand and Dust Storm Warning Advisory and Assessment System to enhance the ability of countries to deliver early and accurate sand and dust storm forecasts, observations, information and knowledge to users.[43] This system provides global and regional forecasts of dust threat and has established regional centres for the Americas, Asia, and Northern Africa, Middle East and Europe.[44]

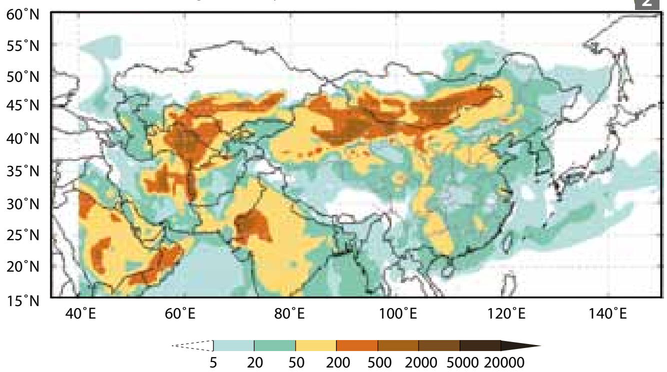
Integrated land and water management efforts encompass agricultural activities, and the Food and Agriculture Organization promotes conservation agriculture to address threats in arid regions. In 1992, a network called the World Overview of Conservation Approaches and Technologies (WOCAT) began to collect information about conservation

Online dust forecast by the World Meteorological Organization Sand and Dust Storm Warning, Advisory and Assessment System Regional Centres

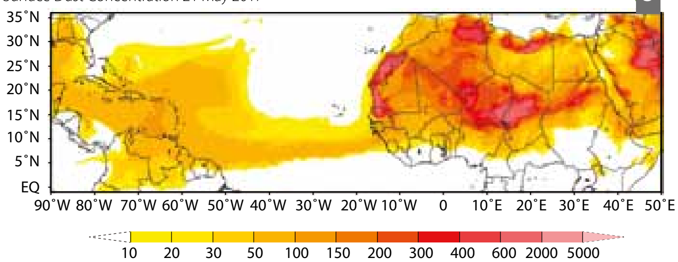
Dust Surface Concentration (ug/m³) 18 May 2017 (1)



Surface Dust Concentration (ug/m³) 18 May 2017 (2)



Surface Dust Concentration 21 May 2017 (3)



agriculture and sustainable land management practices from specialists. In 2014 the network was formalized into a consortium and recognized by the UNCCD as the recommended source of data on best practice. In 2017, WOCAT involves more than 2 000 registered users, over 60 participating institutions, and around 30 national and regional initiatives.[45]

Agriculture is responsible for nearly 70 per cent of all freshwater withdrawals.[46] Conservation agriculture also promotes water use practices that prevent water scarcity and desertification and that reduce the formation of sand and dust storms. The 2030 Water Resources Group has brought together case studies from around the world of currently available, replicable and practical solutions for water management. The solutions have been collected in an online catalogue 'Managing Water Use in Scarce Environments' that is meant to inspire action and use by policy and decision makers.[47] Many of the solutions have clear relevance to reducing sand and dust storms.

Finally, improved international integration and coordination of research is needed to reduce critical uncertainties on the interaction of dust with global biogeochemical processes and climate systems; to improve methods for monitoring, prediction and early warning systems; to assess the economic impacts and costs of sand and dust storms and related mitigation measures; and to improve the effectiveness of measures before, during and after interventions.

1 Northern Africa, Middle east and Europe Centre
https://sds-was.aemet.es/

2 WMO SDS-WAS Asian Center
http://eng.nmc.cn/sds_was.asian_rc/

3 Pan-America Regional Center
http://sds-was.cimh.edu.bb/

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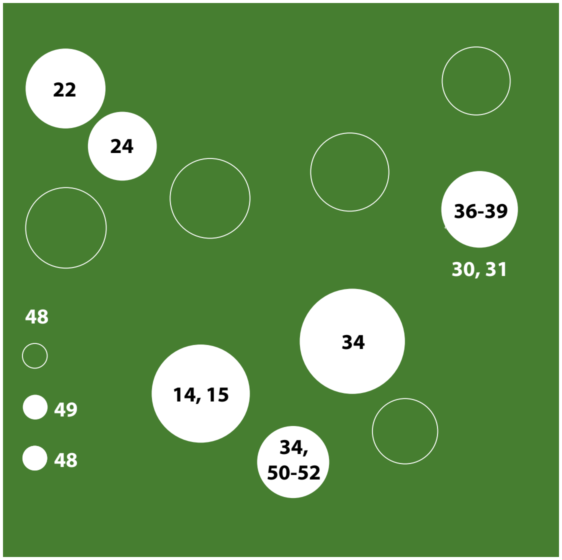

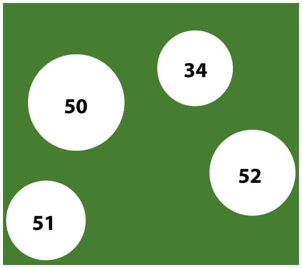

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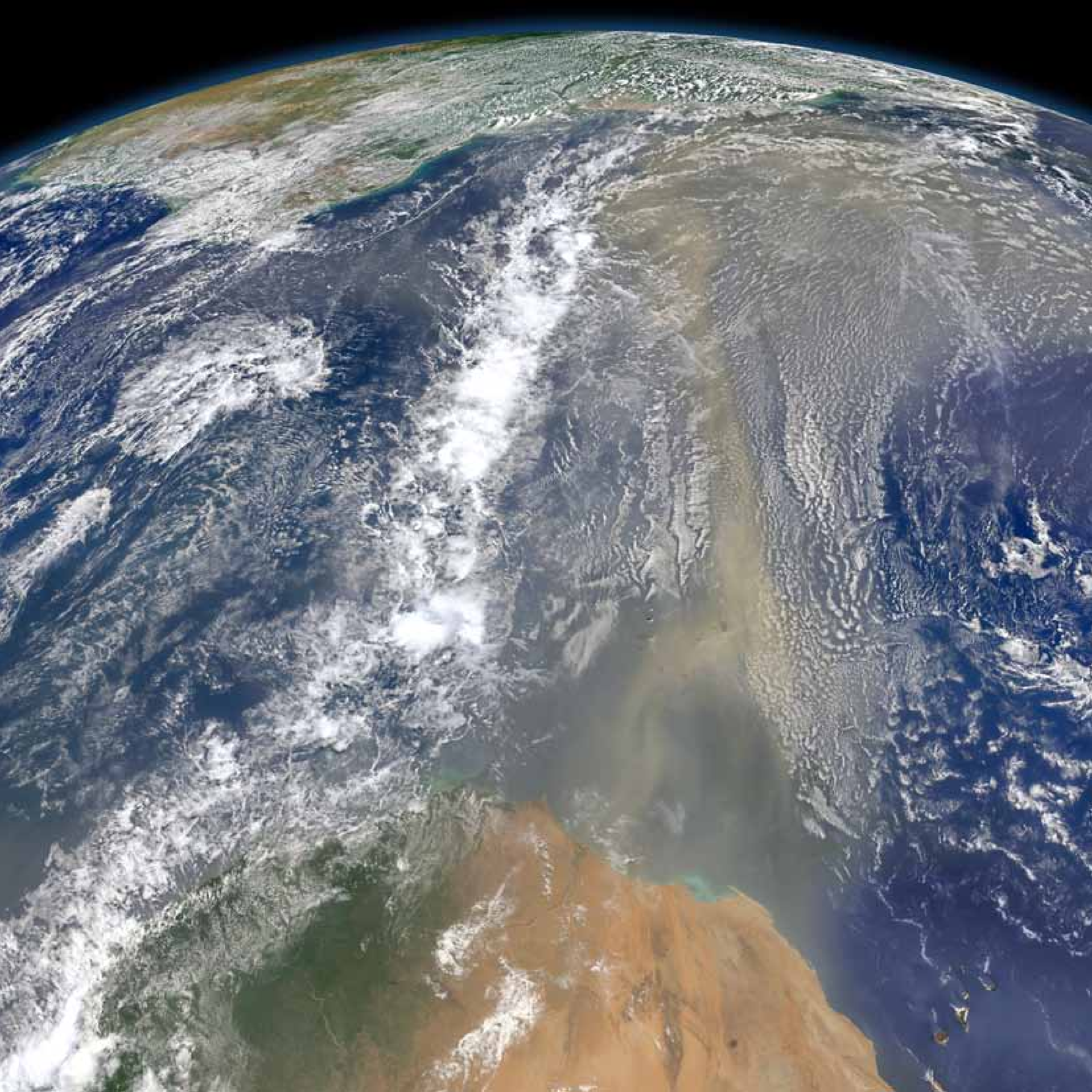
A dust plume blowing from western Africa towards the Amazon Basin and the Gulf of Mexico, 25 June 2014. At least 40 million tonnes of Saharan dust is delivered to the Amazon Basin each year. Photo credit: Norman Kuring/NASA OceanColor Group



Enkanini informal settlement, Western Cape, South Africa
Photo credit: MrNovel / Shutterstock

Solar Solutions: Bridging the Energy Gap for Off-Grid Settlements

The off-grid urban population

Access to electricity is fundamental to sustainable development and necessary for basic household activities.[1] The lack of electricity can hamper productivity, limit opportunities for income generation and inhibit the ability to improve living conditions. Nearly 1.1 billion people worldwide are still living without electricity and another one billion are connected to unreliable and unstable electricity grids.[2,3] While significant progress has been made in recent years to increase grid electrification in countries like India and Nigeria, projections suggest that by 2030 nearly 780 million people could still be off-grid.[2] New and sustainable approaches to providing electricity that transcend the established norms are required, especially if we are to achieve the Sustainable Development Goal of universal access to affordable, reliable and modern energy services by 2030.

Rural areas have the greatest need for off-grid energy solutions, however the issue of electricity access facing urban residents should also be recognized. About 48 per cent of developing countries' populations now reside in cities, and the proportion may rise to 63 per cent by 2050.[4] Nearly a quarter of the urban population lives in various forms of informal settlements and the proportion is much larger in the rapidly growing cities of Africa, Asia and Latin America. The mounting demands for infrastructure and basic services—suitable housing, clean water and sanitation, and affordable and reliable energy forms such as electricity—tend to exceed the capacities of cities to meet the needs of all their inhabitants.

Provision of basic services for urban informal settlements is a significant challenge that varies according to how the municipal government defines eligibility for the supply of formal urban services. In the case of electricity access, challenges include land rights, recognition by authorities of legal occupancy, stakeholders' reluctance to engage, price of services, return on investment made by the electricity provider, and distance to existing grid and other necessary infrastructure.[5]

Lack of formal possession of the property on which a shack or house stands can exclude an application to the local or national electricity utility for a formal connection.[6] Electricity providers worry about profitability when servicing these communities: the first concern is the high rate of default on financial commitment and the second concern is the low rate of electricity consumption. Both issues relate to the low and undependable incomes of these communities' occupants.[5,6]

Fire hazard is a major threat in informal settlements due to the high population densities, the close proximity of the structures and dwellings, and the common use of kerosene or paraffin lamps, candles and other open flame energy sources.[7,8] Those fire hazards, and associated indoor air pollution, should help persuade a variety of stakeholders to install electricity.[9-11] However, once a few connections are installed, illegal and overloaded electricity connections often abound and pose significant safety risks for informal settlements, in the familiar form as fire hazards but also as electrocution. Surveys from South Africa show that in some informal settlements, over 30 per cent of the population use an illegal connection as their main electricity source.[5]

Even when a grid connection has been established, power supply can be unreliable. In some developing countries, households with long established grid connections may adapt to regular blackouts by scheduling water pumping and battery recharging for periods when the power supply is most reliable.[12] Even developed countries experience power outages, sometimes completely when severe storms hit but also as rolling blackouts, also called rotational load shedding or feeder rotation, when other extreme events, such as heat waves, strain the supply.[13] Too often, households in developing and developed countries invest in small diesel generators for back up. These generators pollute, with greenhouse gas emissions, noxious exhaust and annoying noise.[12,13]

Earth at night, 2016

Photo credit: NASA Earth Observatory/NOAA NGDC

The solar photovoltaic evolution

For decades, multilaterals, governments and non-governmental organizations have promoted decentralized solar photovoltaic systems in inaccessible rural areas, particularly to power public services, such as school and clinic lighting, information exchange and communications, community pumping and vaccine refrigeration.[14,15] Now, they can be considered as an alternative solution to grid electricity anywhere in developing countries where governments and the private sector cannot meet expectations for the expansion and maintenance of a grid network, including informal urban settlements.[14]

Recent years have seen an increased popularity of small distributed solar energy systems in low-income communities in Africa and Asia, where at least 95 per cent of the off-grid population reside.[16-18] These systems range from a stand-alone lantern with a built-in solar panel, a battery and a light emitting diode (LED) bulb, to a small, or pico-scale, solar unit equipped with a panel, at least one LED bulb, and a battery with USB charging outlets for a mobile phone or even a low-power appliance.[3] Prices range from US$10 for a solar lantern to US$50 for a pico-solar system.

These relatively affordable solar lighting products offer a better return on investment, particularly considering their long lifespans in contrast to the recurring cost of kerosene or paraffin for lanterns, dry-cell batteries for torches, or candles.[3,19] More powerful solar home systems include similar features and can support several lights and relatively larger household DC appliances such as a radio, fan, television or even a refrigerator.

Many of the off-grid population in sub-Saharan Africa spend about 10-30 per cent of their household income on their kerosene supply and in sub-Saharan Africa and Asia kerosene lighting costs the poor nearly US$15.7 billion per year.[20,21] The replacement of kerosene lanterns by solar lanterns translates into significant cost savings for households over the lifetime of the solar lantern as well as a significant reduction of the use of open flames in lanterns and candles, reducing exposure to indoor air pollution and the risk of fire hazards in informal settlements.[11,21-23] These pico-solar and solar home systems have become attractive to a greater range of the off-grid population than ever before.

The continuing price reductions of the various photovoltaic components and rapid advances in technologies are notable. The cost of crystalline silicon solar cells dropped 85 per cent between 2008 and 2016 due to increased manufacturing efficiency and economies of scale.[21]

Advances in LED technology resulted in improved efficiency—more light emitted per electrical input. Highly polluting lead acid batteries are becoming obsolete, replaced by higher performance lithium ion batteries that provide higher energy storage capacity, longer service life, and faster and more efficient recharging.[24] While the batteries are the most expensive component of a solar home system, the price of lithium-ion batteries dropped nearly 65 per cent within five years, and is expected to fall further due to their widespread use in laptop computers and other devices.[21]

Kerosene wick lamps made from recycled cans
Courtesy of Evan Mills

Off-grid solar

The off-grid population

Middle East and North Africa
Urban: 1 million
Rural: 12 million

South Asia
Urban: 12 million
Rural: 327 million

Sub-Saharan Africa
Urban: 113 million
Rural: 504 million

East Asia and the Pacific
Urban: 5 million
Rural: 50 million

Latin America and the Caribbean
Urban: 5 million
Rural: 14 million

By 2030 nearly **780 million** people globally- could remain off-grid

Solar photovoltaics

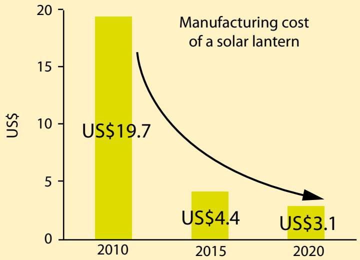
These solar photovoltaics range from a **solar lantern**, a small solar system or **pico-solar** supporting at least one light bulb, to a **solar home system** with a larger battery capacity that can power multiple LED lightings and household DC appliances.

Solar photovoltaics are becoming mainstream among off-grid populations in rural and urban areas particularly in Africa and South Asia

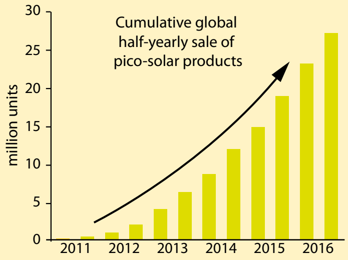
Each year the off-grid population in Africa and South Asia spend an estimated **US$14.4 billion** and **US$ 6.6 billion**, respectively, on kerosene and lamp, battery torch and candle.

Solar lanterns and pico-solar systems are replacing traditional **inefficient lighting** sources

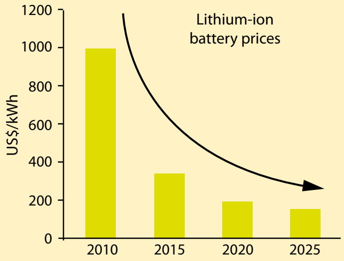
Prices are dropping



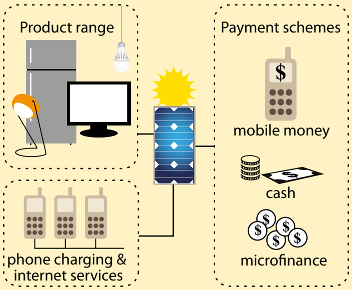
Sales are rising



Battery costs are falling



Diverse business models



Challenges and opportunities

The **well-designed policies** and clear vision on renewable energy combined with advancing **technology** and **market innovation** could encourage today's off-grid communities to remain on the clean energy and **sustainability pathway**

E-wastes generated by solar products are projected to increase exponentially in coming decades. This will require environmentally sound management of spent products, but at the same time, present business opportu-nities for **recycling markets**

Off-grid solar systems could provide **hundreds of thousands of jobs** throughout the value chain

UN Environment estimates that the transition to efficient off-grid lighting is likely to create **30 times more jobs** than the fuel-based lighting does

Innovative marketing of off-grid solar energy

A key factor that allows solar-powered electricity to enter the market in informal settlements is innovation in business models.[16,25,26] Although the retail prices of pico-solar and solar home systems may be manageable for some, those in the lowest-income portion of the off-grid population cannot afford the initial equipment purchase. Many small-scale and start-up companies are offering financial schemes to help consumers overcome the barrier of upfront costs, with the aim of eventual profitability through capture of the market's high volume.[16,17,19]

Several of these schemes arrange for people to pay the same small amounts they were paying for kerosene. In a pay-as-you-go scheme, customers pay a small instalment on a solar power system and make regular payments on a daily, weekly or monthly basis. If payment is not made, the system is automatically deactivated. After completing payments, customers own the product. This scheme is often used in connection with existing mobile-phone money services, which are well-established businesses in regions such as some parts of sub-Saharan Africa.[17,27]

In India, nearly a third of its urban population live in informal settlements.[28] A survey of Delhi's informal settlements estimated an average monthly income of only US$105 (INR 6 676) per dweller and 90 per cent of which is spent.[29] Most companies provide financing schemes to serve the most marginalized families who are rural migrants to informal settlements in India's rapidly growing cities.

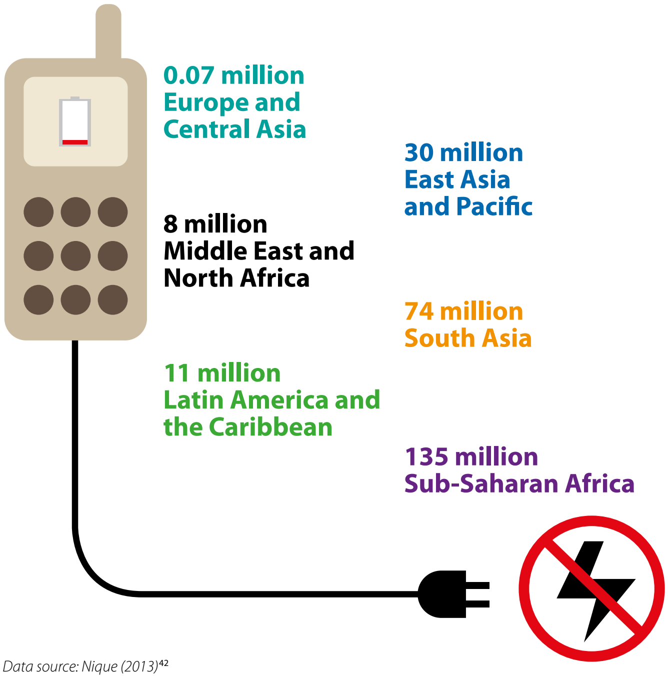
Without a formal address and less than a decade in their location, the families cannot access traditional financing services. Some companies employ local men and women who go door-to-door in the informal settlements offering products with affordable payment terms.[30] Customers can purchase a solar lantern on a 5-8 week payment plan. Some companies have evolved further to develop business relationships with microfinance institutions to expand financing options for lowest income consumers.[31]

In South Africa, even after the post-apartheid electrification and housing program, close to a quarter of the population live in informal settlements without electricity.[32] A sustainability

Video: Why solar power is spreading so fast in Africa

Video Link: https://www.youtube.com/watch?v=tkvbZ0ADmz0 *© The Economist*
Photo credit: Gabriela Gemio Beltrán

Estimated number of mobile phone subscribers living off-grid



Data source: Nique (2013)[42]

project led by the University of Stellenbosch aimed to improve the living conditions of the 4 500 inhabitants of Enkanini, an off-grid informal settlement in Western Cape Province.[33-35] Using energy-efficient technologies, the interventions included reorienting dwellings to optimize their passive solar potential, improving the building insulation and harvesting water.

The project ran an off-grid solar power business that served the settlement with an expectation to scale it up as a franchise model for other off-grid settlements. Solar home systems—a solar panel, two indoor LED lights, one TV, an outdoor spotlight and phone charging facilities—are offered to residents on a fee-for-service basis. Customers pay an installation fee of US$14 (ZAR 200) and monthly lease payments of US$11 (ZAR 150).[33]

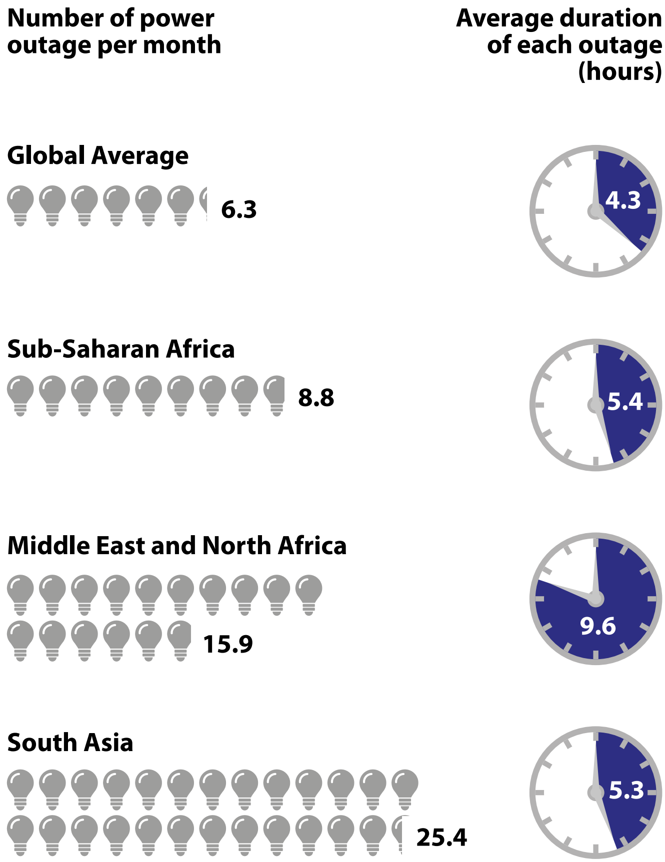
A company established by the project employs staff from the settlement and is responsible for the deployment and maintenance of the system. This business model has now been adopted by some municipal authorities for other informal settlements in South Africa.[36-38]

Pop-up solar kiosks are another unique form of business innovation that exploits solar energy to serve off-grid

Video: In high demand: Solar Kiosk in Rwanda

Video Link: https://www.youtube.com/watch?v=QpukLasOnSo *© DW English*
Photo courtesy of Henri Nyakarundi/African Renewable Energy Distributor

Frequency and duration of grid power outage
(showing only regions above global average)



Data source: The World Bank's Enterprise Surveys, http://www.enterprisesurveys.org

communities outside of their homes. A small mobile solar kiosk is equipped with a few solar panels and a lithium-ion battery unit that can power 10-80 mobile phones simultaneously, and some even offer Wi-Fi services.[39,40] Larger solar kiosks are stationary and fitted with rooftop solar panels.[41] Functioning like a grocery store, it offers a range of goods such as solar products, mobile phones, consumables, medicine, as well as phone charging and internet services. A variety of solar kiosks are spreading across Africa where 135 million mobile subscribers live without electricity in their homes.[42]

Continuing on the pathway of renewable energy

A pico-solar system is only the first step for a family to lift themselves out of energy poverty. Whether supplying electricity to dwellings in rural, peri-urban or urban locations, a small system may be sufficient at first, but once their purchasing power grows and the price continues to drop, people will look for more capacity. This presents an array of opportunities to continue along the solar pathway, rather than turning to grid power sourced from coal and oil. In 2016, fossil fuel accounted for about 80 per cent of electricity generation in Africa and 60 per cent in South Asia.[43,44]

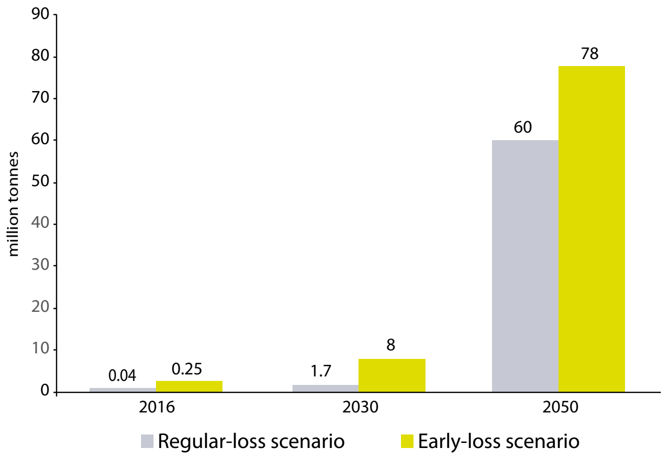
To remain on the sustainability pathway and reinforce renewable energy solutions, some factors should be considered, given their influence on solar market expansion. These include needs for quality standards, consumer awareness, financial assistance, e-waste management, and re-orientation of government policies.[17,25]

In many developing countries, solar products have been available for years, if not decades. Often the products were of low quality or short life span. Decisions to stay with off-grid solar may depend on today's impression of the products

Video: Solar energy for Africa by 2030

Video Link: https://www.youtube.com/watch?v=Bb8Su6OeWYw *© CGTN Africa*
Photo credit: MrNovel / Shutterstock.com

Overview of global PV panel waste projections 2016-2050



Source: Adapted from IRENA and IEA-PVPS (2016)[47]

available in the market. Negative experiences with substandard generic products could damage the receptivity of today's and tomorrow's potential consumers. Two concurrent paths could help remedy the problem: One is to establish higher quality standards for the products themselves and take-back and recycling guarantees by the service providers. The second path is to raise awareness among consumers about the higher quality that is now standard for the products themselves, for the services that accompany the transaction, and for the extended and enabling payment schemes.[25]

A lack of working capital for companies, particularly those that provide end-user financing, may limit market development. Supportive programmes can be devised to mitigate these challenges and the innovative business models already in play are good examples of what is possible.[5,16,17,25] Future demand for solar home systems with higher capacity will also help expand the current markets and further prompt commercial interest and investment from private investors, development banks and donors. In 2016, at least US$60 million was invested in two companies in Africa that offer larger and higher priced solar home systems than the original pay-as-you-go operators.[45] These pay-as-you-go solar companies are likely to aim at creating a new market of higher income consumers who may already be connected to an unreliable electricity grid.

Another challenge involves the e-wastes generated by the growing volume of products in use. While lithium-ion batteries are considered less toxic compared to lead acid, they still have the potential to pollute the environment, given the variety of chemical materials contained in the batteries.[46] Currently few manufacturers are supplying replacement parts or recycling old batteries at the end of their life cycle.[47,48] Similarly, crystalline silicon panels are a cause of concern as they also contain toxic substances, such as cadmium and lead. If customers could upgrade their consumer goods for better products through take-back programmes, recycling markets could become viable and reduce the risk of contamination. It should be noted also that e-waste regulations might not exist to deal specifically with solar panels in many countries where small solar systems have gained popularity.[47]

The challenges involving government interventions include uncertainties about possible future policy choices regarding off-grid electrification in national, regional and municipal strategies and implementation. Also, many countries have a long history of subsidizing citizens' kerosene purchases to quell dissatisfaction over unmet promises for grid supply. While some recommendations push for elimination of kerosene subsidies, another path is to allow off-grid customers to apply the subsidies to the purchase of their solar power systems. Once those are paid off, questions remain whether the subsidies should then continue. As well, off-grid power supply companies suggest an end to fiscal and import barriers, such as high import tariffs and value-added tax on solar power products, which may significantly increase the price of the products.[19,25]

Finally, there are challenges regarding capacity development, beyond the public awareness effort. Companies, and communities need a qualified and skilled workforce to support the development of the sector. Training courses and apprentice programmes, especially for members of the local community that will make up the market, should be available.[3,25] Off-grid systems will provide hundreds of thousands of jobs throughout the value chain in the near future and could provide a path out of poverty for those who learn about installation and maintenance of larger home solar systems.[25,49] A UN Environment's study in West Africa estimates that the transition to efficient off-grid lighting is likely to create 30 times more jobs than fuel-based lighting does.[50] With the right policies and regulations on renewable energy and a clear vision of future possibilities, today's distributed solar powered systems could remain the energy of choice for off-grid communities in the rural and urban areas. This could be a key component of accomplishing Sustainable Development Goals for universal access to affordable, reliable and modern energy services by 2030 and for eliminating poverty.

A woman trained by the Barefoot College to install, repair and maintain solar systems for her home in Rajasthan, India

Photo credit: Knut-Erik Helle, licensed under CC BY-NC-ND 2.0

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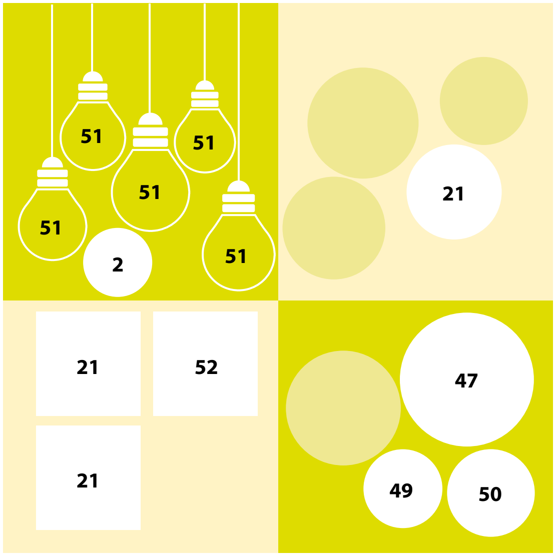

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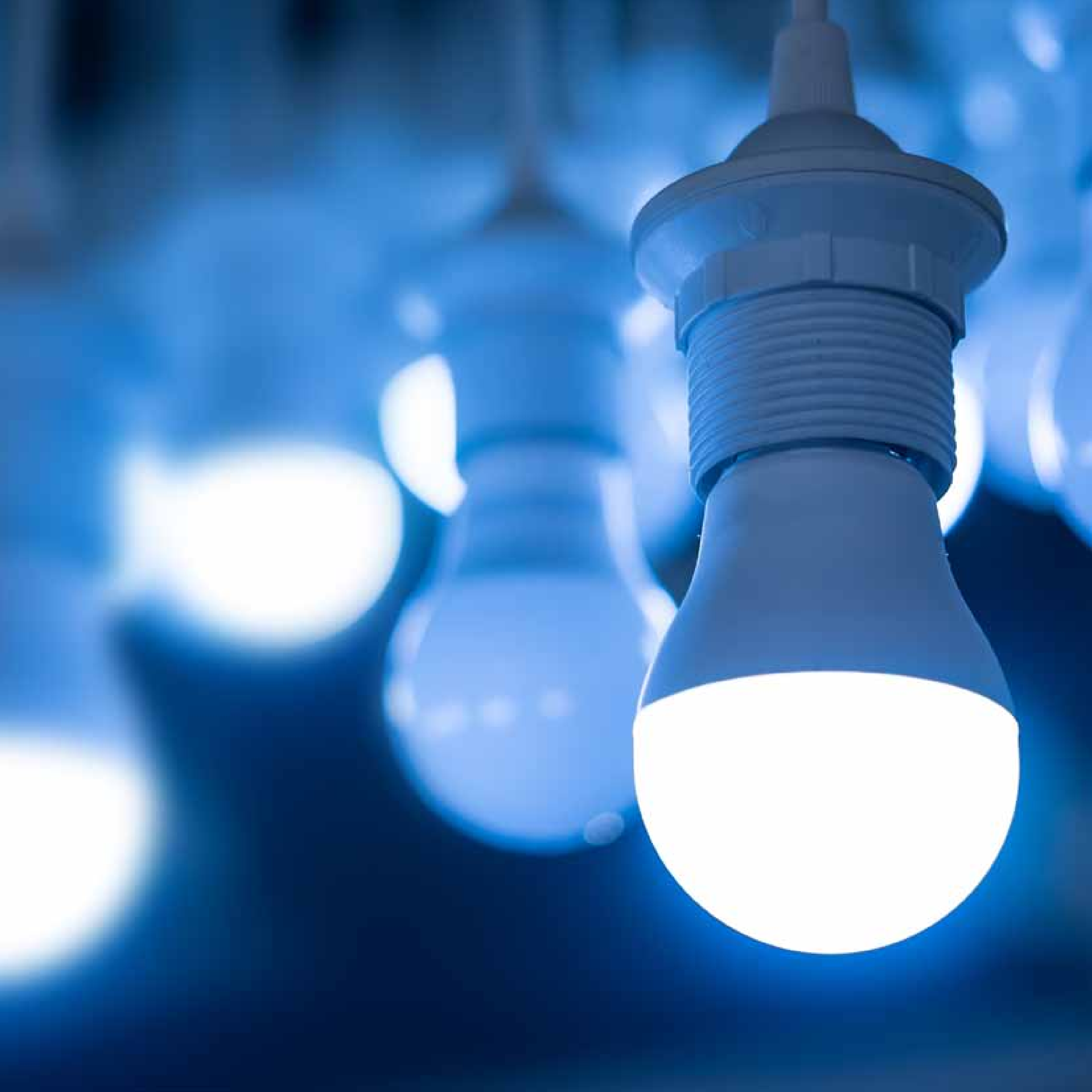


Thousands displaced by floods and conflict near Jowhar, Somalia in 2013
Credit: UN Photo/Tobin Jones

Environmental Displacement: Human mobility in the Anthropocene

What is Environmental Displacement?

We live in an era of unprecedented mobility: movement of ideas, goods, money and, increasingly, of people. Two hundred and fifty million people live and work outside the country of their birth. Another 750 million migrate within their own countries.[1]

The scale and pace of human mobility coupled with a global population that is predicted to peak at more than 9 billion by the middle of this century represents our new demographic reality. Migration is a hugely important driver of development and progress, offering opportunities to individuals and families, as well as spreading ideas and connecting the world. But the issue has also proven to be politically divisive.

At the same time we live in an era of unprecedented environmental change. Human activity has reshaped our planet so profoundly that scientists suggest that we have entered a new geological epoch they label "the Anthropocene".

Environmental change and environmental degradation—desertification, deforestation, land degradation, climate change and water scarcity—are fundamentally redrawing the map of our world. Environmental degradation affects where and how people are able to live. It drives human displacement and forced migration by threatening lives and making people's livelihoods untenable, particularly the poorest and most vulnerable.

Meanwhile, armed conflicts lead to further flows of people fleeing violence either within their countries (internal displacement) or across international borders (refugees). Analysis of civil wars over the past 70 years indicate that at least 40 per cent are linked to the contested control or use of natural resources such as land, water, minerals or oil.[2] By the end of 2016, more than 65 million people were refugees or internally displaced—a number greater than at any time since the end of the Second World War, and 128 million people required humanitarian assistance.[3,4]

Environmental issues have been one factor in population movements ever since humans first left Africa. Those factors have always been varied and complex, though it is important to recognize that, historically at least, environmental degradation has tended to 'set the stage' for displacement but other factors of vulnerability such as poverty and lack of opportunity are often key drivers of displacement. What is different now is that the degree of environmental degradation and the ability to move are combining to create a push and pull effect that is on a scale never seen before.[5]

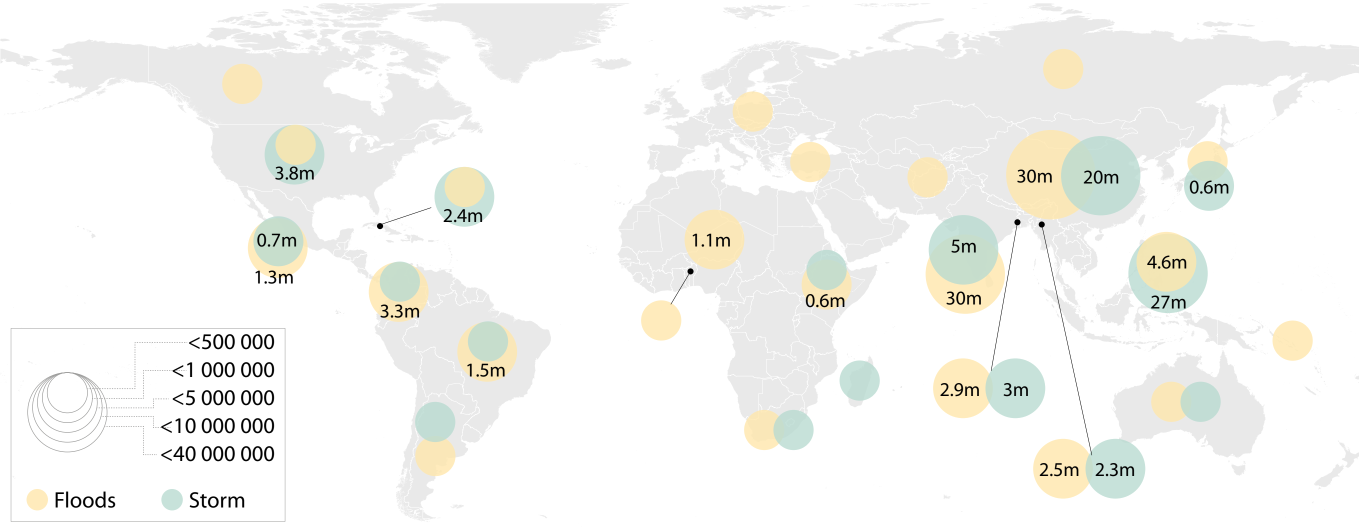
Population growth is leading to more people living in marginal and environmentally vulnerable areas.[6]

Already an average of 26.4 million people are displaced from their homes by natural disasters each year.[7] This is equivalent to one person every second. But we cannot become anesthetized by the figures. Every single statistic is a personal story of loss—of worlds turned upside down, opportunities closed, education foregone.

The interlacing trends of climate change, population growth, rising consumption, large infrastructure projects and environmental degradation may lead to greater numbers of people displaced in future. This is particularly likely if these trends occur in the context of inadequate responses from governments and the international community to build the resilience of countries and communities to these changes. The most commonly cited figure is that there could be as many as 200 million people displaced for environmental reasons by 2050.[5]

That would mean that, in a world of nine billion people, one in 45 would have been forced from home for environmental reasons, and entire low-lying island territories may have to be abandoned. Addressing such displacement may be the defining environmental challenge of the 21st century.

Number of people displaced by floods and storms in selected countries in 2008-2016



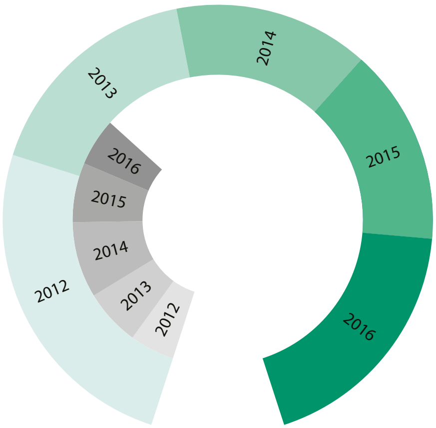
Data source: Internal Displacement Monitoring Centre, www.internal-displacement.org/database

Understanding environmental displacement

Although the issue of irregular migration has gained prominence in recent years as a result of Europe's "migration crisis", it is by no means a uniquely European challenge. Just as migration occurs across the globe, every corner of the world has the potential to be affected by environmental displacement.

For example, models project that the Asia and the Pacific region will see a growth in displacement as the impacts of climate change gather pace.[10,11] Coastal areas, large deltas, and small islands are vulnerable to sea level rise and particularly exposed to cyclones. The Pacific small island state of Tuvalu, whose highest point is just five metres above sea level, may have to be evacuated entirely in the next 50 years, the Maldives in the next 30. Already several states are starting to plan for the eventual relocation of some or all their populations: In 2014 President Anote Tong of the Republic of Kiribati bought land in Fiji as an insurance policy against rising sea levels.[12]

Number of people displaced by conflicts and weather-related disasters from 2012-2016



41 million people displaced by conflicts
117 million people displaced by weather-related disasters

Data source: Internal Displacement Monitoring Centre, www.internal-displacement.org/database

The African continent, meanwhile, has more countries affected by displacement than any other continent or region, and in 2015 was hosting more than 15 million people who had been displaced within their own country for a number of reasons, including those linked to the environment.[13] More than half of the world's fragile states are in sub-Saharan Africa, and the continent is particularly prone to droughts, which increase the risk of food scarcity.[13,14]

Labels matter

One contentious issue is whether people displaced by environmental degradation and climate change should be called "environmental refugees", "environmental migrants" or "environmentally displaced people". This is not just semantics. Which definition becomes generally accepted has real implications for the obligations of the international community under humanitarian law and the rights of the people displaced.

After the Second World War, international policy makers judged that the term 'refugee' should be restricted to "A person who, owing to a well-founded fear of persecution for reasons of race, religion, nationality, membership of a particular social group or political opinions, is outside the country of his nationality and is unable or, owing to such fear, is unwilling to avail himself of the protection of that country".[8]

Campaigners have used the phrase "environmental refugee" to convey the urgency of the issue. However, the use of the word "refugee" to describe those fleeing from environmental pressures is not accurate under international law. The majority of people forced out of their homes by environmental change will likely stay within their own borders, but there may be no possibility of return for areas inundated by rising sea levels.[9]

Partly for lack of an adequate definition, environment-driven population movements are often invisible, particularly when the displacement happens over time. No single international institution is responsible for collecting data on their numbers, let alone providing them with basic services. Unable to prove political persecution in their country of origin, they fall through the cracks in international humanitarian law. This report uses the term "environmental displacement", acknowledging that it is not a universally accepted term but in the hope that it conveys a reasonably accurate impression of the increasing phenomenon of forced population displacement linked to environmental degradation and climate change.

Environmental Displacement

Land Degradation, Desertification and Drought

Severe drought and food insecurity has **displaced 761 000 people** in Somalia since November 2016

The ecological restoration of land over 50 000 km^2 across Burkina Faso, Mali and Niger contributes to the **reversal of outward migration**

Drought is projected to become more intense, frequent, and protracted because of climate change

50% of agricultural land in Latin America is subject to desertification by 2050

Drylands are becoming more arid and less productive due to unsustainable use of land and water, and climate change. One third of the world's population live in drylands.

Natural Disasters

IPCC predicts frequent **extreme rainfall** making landfall in North and Central America, East Africa, West Asia, South Asia, Southeast Asia, East Asia, Australia and many Pacific islands

117 million people were displaced by weather-related disasters from 2012-2016

Climate change influences the likelihood, frequency and intensity of extreme climate events. Extreme weather events can make areas uninhabitable, and displace populations temporarily or permanently.

Wind speed of **tropical cyclones** is becoming stronger, and likely to cause serious damage

Demand and Competition over Natural Resources

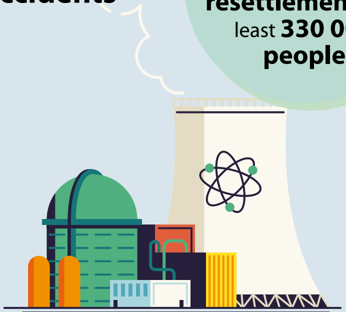
Over the past 70 years, at least **40% of all conflicts** within national borders are related to natural resources

Competition over increasingly scarce natural resources – land, water, timber, oil, minerals – can create tensions and ignite conflicts among users. In many cases, tensions can lead to violent conflicts and large-scale forced displacement.

Forced dispossession of land are increasingly common in Latin America as a result of mining, logging, plantation activities

Industrial Accidents

The 1986 Chernobyl nuclear meltdown forced the **evacuation and resettlement** of at least **330 000 people**



150 000 people were displaced due to **radiation leaks** from the Fukushima nuclear power plant in Japan. The return and resettlement remains uncertain.

Serious industrial accidents can leave large areas polluted, and force people to abandon their homes and resettle elsewhere. Long-term health, social, economic and environmental impacts of industrial accidents can complicate their permanent return.

Sea Level Rise

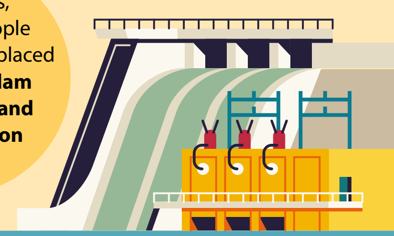
In the Solomon Islands, five vegetated **reef islands have vanished in recent decades** due to sea level rise and wave exposure. Communities have relocated to a higher volcanic island nearby.

A study of migration patterns in developing countries from 1970 to 2000 suggests that people relocate away from marginal drylands and drought-prone areas towards the coastal zone **prone to floods and cyclones**

Most of the world's megacities are located in the coastal zone and large deltas, where the livelihood of millions of people depend on. Low-lying coastal cities and small islands are vulnerable to flooding, storm surges, shoreline transformation and saltwater intrusion as a result of sea level rise.

Infrastructure Projects

In the 1980s, 10 million people were forcibly displaced each year by **dam construction and transportation projects**



Large-scale infrastructure projects such as dams and roads can result in massive displacement. Meanwhile, large-scale land purchases in developing countries by infrastructure projects and agribusiness, often labelled *land grabbing*, are likely to be prominent cause of future displacement.

The 17-year long construction of the **Three Gorges Dam** on the Yangtze river in China is estimated to have **displaced 1.3 million people.** Many are still facing challenges to resettle

Nor is North America immune to the impacts of environmental displacement. In 2016 the residents of Isle de Jean Charles in Louisiana were the first US "climate migrants" to receive federal funds for their relocation. The US$48 million grant was part of US$1 billion awarded in January 2016 by the Department of Housing and Urban Development to help communities across 13 states adapt to climate change by building dams, drainage systems and stronger levees.[15]

But the picture is complicated. The most vulnerable groups often lack the means or connections to move, and may be trapped in place. Others, such as pastoralists, rely on seasonal migration as a livelihood strategy. Meanwhile, the planned relocation of populations in the face of a particular risk such as major land degradation can act as a release valve, reducing environmental pressures on fragile ecosystems but also, in effect, "exporting" their environmental footprint elsewhere.[16]

It is also important to remember that displacement itself can have environmental impacts, causing environmental degradation that can prolong the humanitarian emergency or worsening relationships with host communities. Informal urbanization or disorganized refugee camps can put pressure on scarce land, water, energy and food resources. Such situations can undermine ecosystem services, lead to health risks from improper waste disposal, and position displaced persons in direct competition with local communities.[17,18]

Video: **Foresight - Migration and Global Environmental Change**

Video Link: https://www.youtube.com/watch?v=zt0UJU0aAVg *© GO-Science*
Photo Credit: Thousands displaced due to flooding in Cap-Haïtien, Haiti, by UN Photo/Logan Abassi

Institutional solutions

The issue of environmental displacement has moved up the political agenda, attracting attention from policymakers, academics, and the humanitarian community. In 2011, the UK Government Office for Science published the results of The Foresight Project, a study of how human population movements across the world could be affected by global environmental changes. The project took two years and involved over 350 leading experts and stakeholders from over 30 countries covering subjects ranging from demographics to economic development to ecology.[16] The Foresight project exposed unanticipated facets, particularly regarding the benefits of migration, as well as assigning new importance to good planning for in situ adaptation where possible, well-managed retreat from threatened locations, and best practice resettlement schemes among host communities.

At the same time the Foresight Project was conducting research, the Norwegian and Swiss governments campaigned for principles to guide responses to the complex challenges of population displacement in the context of climate change and other environmental hazards.[19] This campaign eventually evolved into the Nansen Initiative and then reformed as the Platform on Disaster Displacement. The Platform's mission is to organise towards consensus on rights and protections for people displaced across borders due to disasters and climate change.[20] Since the early 2000s, the International Organization for Migration has been working on the issue and established a special division devoted to Migration and Climate Change.[21] In 2016, the University of Liège in Belgium formally established The Hugo Observatory as the first academic unit dedicated to the topic of environmental migration.[22]

Migration and displacement issues have been increasingly integrated in the 2015 international agreements that set out much of the development framework for the next 15 years. The Sustainable Development Goals include a commitment to 'orderly, safe, regular and responsible migration' as part of Goal 10 to reduce inequality.[23] The Sendai Framework on Disaster Risk Reduction creates a global framework for reducing disaster risk and losses in lives, livelihoods and health, aiming to substantially reduce the number of displaced people globally by 2030.[24] Migration issues were formally integrated into the Paris Agreement on Climate Change with the creation of a Taskforce under the Warsaw Mechanism on Loss and Damage to develop approaches to prevent, minimize and address climate change displacement.[25]

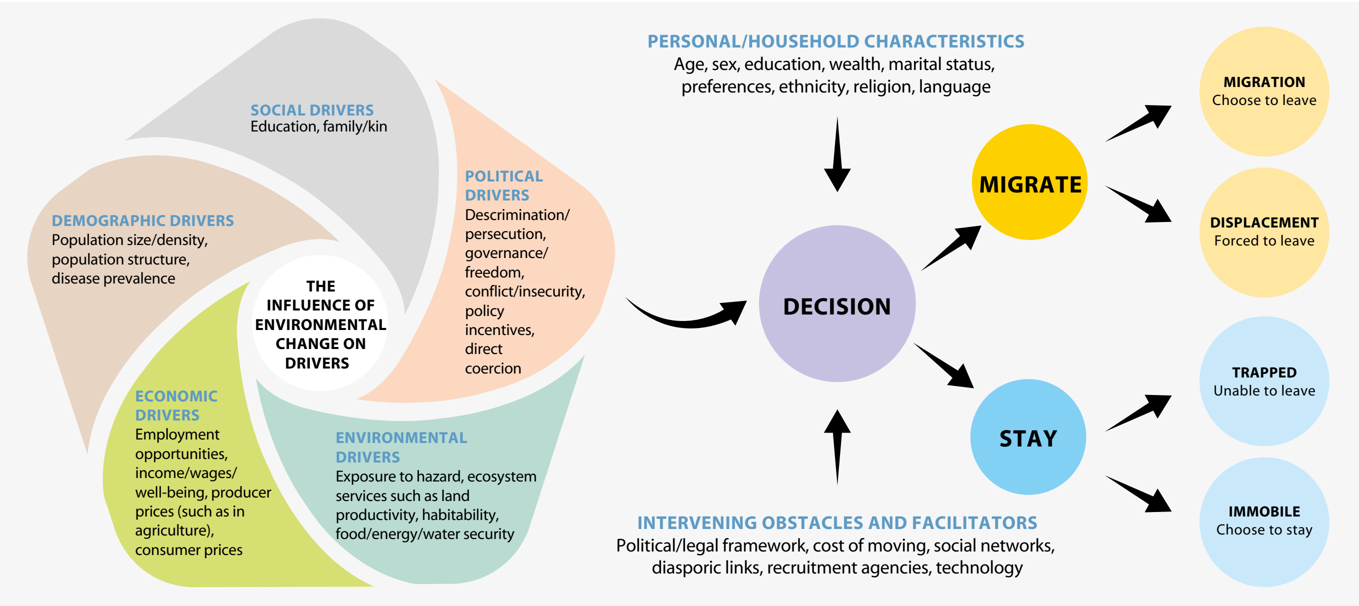
The 2016 UN General Assembly convened a high-level meeting to build international consensus to address the growing challenge of international migration and the increasing flow of refugees. The meeting adopted the New York Declaration for Refugees and Migrants.[26] The declaration includes two annexes: The first is a framework for a comprehensive response for refugees. The second is a roadmap towards the achievement of a Global Compact for Safe, Orderly and Regular Migration, to be presented for adoption at an inter-governmental conference on the issue in 2018.[27]

Video: How climate change impacts human displacement

Video Link: https://www.youtube.com/watch?v=a2nTq67So3U
Photo credit: Grand Dessalines, Haiti after Hurricane Tomas, by UN Photo/UNICEF/Marco Dormino, licensed under CC BY-NC-ND 2.0

Environmental change and drivers of migration

The decision to migrate or stay is largely driven by a range of drivers. Global environmental change further influences the complex interactions of these drivers and can lead to different outcomes in decision making.



Source: Adapted from the conceptual framework of the drivers of migration and the influence of environmental change, adopted by the UK Government's Foresight Project[16]

Dealing with environmental displacement

Environmental degradation and mismanagement are interwoven with the political, economic and social drivers of displacement. We need to better understand, and tackle, those complex factors. Ultimately, unless we can deal with long-term environmental vulnerability, huge numbers of people displaced every year could become our 'new normal'.

The environmental community has an important role to play in building awareness of the ecological drivers of displacement; strengthening the capacity of communities and countries to withstand shocks and environmental change; and helping to plan the relocation of communities likely to be displaced by unavoidable environmental change.

Ultimately displacement is not just a political challenge. As the case of the Iraqi Marshland shows, it is important to think of it as an environmental challenge. The scale of possible future displacement under even moderate climate change scenarios means that environment, humanitarian and displacement-focused actors must work together to build people's resilience in a changing world.

Video: These Americans may become 'climate refugees'

Video Link: https://www.youtube.com/watch?v=TicvZPYuFfg *© CNN*
Photo Credit: Shishmaref, Alaska by Berring Land Bridge National Reserve, licensed under CC BY 2.0

Reviving the Iraqi Marshlands

In the 1950s the Marshlands of Mesopotamia (Al-Ahwar) in southern Iraq were a vast landscape home to half a million people known as the Ma'dan, or "Marsh Arabs". They lived in secluded villages of reed houses, fishing, growing rice and raising water buffalo to support their livelihoods.

However, starting in the 1970s, the Marshlands were devastated as a result of upstream dam construction and agriculture, oil exploration, military operations and most directly by the deliberate drainage of the wetlands by Saddam Hussein as an act of reprisal for the 1991 uprisings against his regime. By 2003, 90 per cent of the Marshlands had been lost and just 20 000 Ma'dan remained. It is estimated that up to 100 000 Ma'dan had fled to refugee camps in Iran and another 100 000 were internally displaced in Iraq.

In 2001, UN Environment sounded the alarm bell on the demise of the marshlands which brought its plight to the international spotlight. Following the Iraq War in 2003, UN Environment launched a project to help restore the marshland, building the capacity of decision makers, demonstrating environmentally sound technologies and monitoring the condition of the marshlands. This was followed with a joint project with the UNESCO in 2009 to support the designation of the marshlands as World Heritage Site. It included the development of a management plan that reflected the unique historical, cultural, environmental, hydrological and socio-economic characteristics of the region.

Since 2003 the wetlands have started to recover, though drought, upstream dam building and continuing conflict have hindered the process. Tens of thousands of the Ma'dan people are now returning to their ancestral home. In July 2016, with the support of UN Environment, the marshlands were inscribed as the first mixed cultural and natural World Heritage Site in the Middle East.

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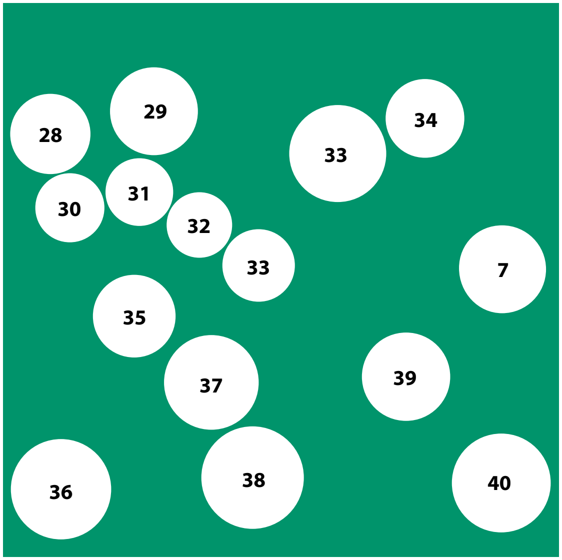
Graphic references



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Forced dispossession of land is increasingly common as a result of expanded plantation of commodity crops
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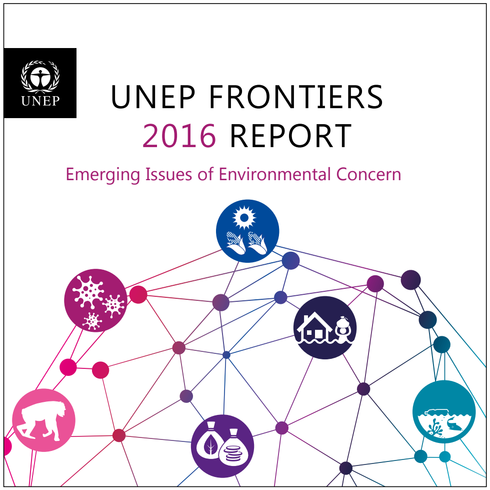

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