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Research for Parliament

Preparing for a changing world

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A full list of contributors can be found in Research for Parliament: Annex A.

A full list of references can be found in Research for Parliament: Annex B.

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POST is an office of both Houses of Parliament, charged with providing independent and balanced analysis of policy issues that have a basis in science and technology. For further information on this subject, please contact the project lead, Dr Jonathan Wentworth. Layout and desing, Lef Apostolakis.

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SUMMARY

This document builds on POST's previous publication, Topics of Interest 2018 (POSTbrief 27), and represents evidence gathered between May 2018 and April 2019. Following feedback from internal and external stakeholders for a more standardised format, the topics included consist of areas of change with a larger volume of evidence attached that are likely to have significant impact, as these are most likely to be of most interest to Parliament. Topics that could be indicative of change but lacking in enough evidence, as may often be the case with emerging cultural change and technologies, were sifted out by POST advisers. Further subjects were then excluded based on workshops with parliamentary staff to ascertain the level of their significance to Parliament, with the areas of change included then peer reviewed by the contributors and organisations listed in Annex A. The subjects are listed under six category headings: demographic change and healthcare; social and cultural trends; geopolitical and governance challenges; environmental pressures and climate change; resource security and sustainability; and technological advance. These categories are based on the drivers of change identified in POSTnote 500, Towards 2020 and Beyond, in 2015.

These summaries of change are not predictions, but subjective judgements about rapidly evolving areas. For example, with high technological growth it becomes difficult to predict what technological tools will be available within a decade; CRISPR-Cas9 was first harnessed for genome editing in 2012, was causing ethical concerns by 2014, and used to alter the genomes of twin baby girls born in 2018 in China. The summaries are rather intended to help sketch out the implications of possible areas of change, which may or may not be desirable. Low probability but high impact events (or wildcards), such as the eruption of a super volcano or a pandemic, could make all such considerations irrelevant. However, deciding what is desirable in the future may help inform policy priorities, and without such debates change may be forced onto policy-makers by foreseeable contingencies. Although too large to be the subject of a POST publication, these areas of change will inform the deliberations of the POST Board to identify priorities for POST's future work programme.

DEMOGRAPHIC CHANGE AND HEALTHCARE

Urbanisation and health Advanced technology in healthcare Cancer treatments

URBANISATION AND HEALTH

Over half of the world's population live in urban areas, and this is projected to increase to 68% by 2050.[4] Cities often offer better employment opportunities, housing and education, and improved access to healthcare and transport. Urban populations are usually healthier than rural residents, however, this is not a holistic picture and extremes of disparity and high levels of deprivation also exist within cities.[5] Health challenges in cities relate to water, environment, violence and injury, non-communicable diseases (NCDs such as cardiovascular diseases, cancers, diabetes and chronic respiratory diseases), unhealthy diets and physical inactivity, harmful use of alcohol, as well as the risks associated with disease outbreaks. The physical environment of a city has been shown to influence physical and mental health, how people behave, the quality of their social interactions, and their use of services.[6]

Overview of area

The number of people living in cities is increasing, with the most urbanised regions including North America (with 82% of its population living in urban areas in 2018), Latin America and the Caribbean (81%), and Europe (74%). However, the growth in urban population has not been experienced everywhere – Africa remains mostly rural, with 43% of its population living in urban areas, and some cities have experienced population decline in recent years. Most of these are located in countries with low fertility rates and where overall population sizes are stagnant or declining. Economic contraction and natural disasters also contribute to decline in urban populations.[7]

Living in a city can provide more choice in employment, housing and education opportunities and better access to primary healthcare and emergency healthcare services.[8] People living in cities are, on average, wealthier, more educated, and more densely concentrated than their rural counterparts; factors known to be beneficial in improving population health by facilitating the delivery of services to a more aware and health-conscious population.[9,10] However, certain characteristics of cities make them less conducive for improving population health. Slums, for example, are characterised by extremely overcrowded conditions, limited access to safe drinking water or sanitation, poor housing conditions, and lack of secure tenure.[11] According to the World Health Organization (WHO), one in three urban dwellers live in slums; a total of 1 billion people worldwide.[12] Cities can promote unhealthy lifestyles through sedentary behaviour and cheap and convenient diets that depend on processed foods rich in fat and sugar and low in nutrients.[13,14,15] Such lifestyles present a serious threat to population health, particularly for more disadvantaged groups.[16] This is likely to be compounded by rising levels of obesity and an ageing population. Although young people account for a relatively high share of the total number of inhabitants in cities in Europe,[17] as the proportion of older people increases, it is likely that the numbers living in cities will also increase.[18] The health of urban populations varies both within and between countries. A recent review found that in developing countries, living in cities was associated with a lower total fertility rate, lower odds of giving birth, and a lower risk of undernutrition, but a higher risk of being overweight, in children. Common risk factors for chronic diseases were more prevalent in urban areas.[19] Within countries, the urban poor typically experience more health disadvantages.[20]

The design of urban environments can help to reduce health risks associated with city living, such as NCDs.[21] The Royal Society for Public Health suggests that "a healthy high street environment is one in which there is clean air, less noise, more connected neighbourhoods, things to see and do, and a place where people feel relaxed. The architecture of the high street would foster active urban design principles, including pavements, seating, shade and shelter. Above all the high street would provide a safe environment."[22] Urban parks offer potential to support healthier lifestyles,[23] however they are under pressure,[24] and evidence suggests they are under-utilised, with usage varying amongst population groups.[25,26]

Implications and challenges

- The extent that policy can be sufficiently joined up to enable it to interconnect the fundamentals of living i.e. health, housing, transport and employment.

Key unknowns

- There is a lack of studies examining the complexity of urban structures and dynamics and their possible influence on urban health and well-being.[27]

- It is difficult to predict how people's attitude to their health and behaviour will change over time. Current trends suggest a growing socio-economic divide, as those who are better off take on board health messages and adopt healthier lifestyles, and those from more disadvantaged backgrounds do not. The improvements seen in young people's behaviour suggest that they may take a more positive approach to their health as they grow older.

- It is unclear how governments will respond to this. The UK government has shown reluctance to regulate the food and drinks industry, but as pressures on health budgets grow this attitude may change and could have an impact on the nation's health.

CHANGING COMMUNITIES

Changing demographics, shifting household compositions, and rising inequality and generational differences are likely to influence the services and infrastructure that serve communities in the UK over the next few decades.[28] The UK population is increasing and ageing.[28] The structure of households is also changing, with more one-person households and multi-generational households.[29,30] This may lead to a rise in services aimed at single people, but it may also require changes to infrastructure to enable older people at-risk of social isolation to be integrated into the community.[31,32] Income inequality between households is rising, which may lead to rises in demand for healthcare services. There is also growing income inequality between older and younger people. Differences in generational preferences, such as lower rates of smoking and drinking and a tendency to participate in informal forms of politics, may also contribute to wider changes in services and institutions.[33]

Overview of area

The UK population is projected to increase by 3.6 million (5.5%) to 69.2 million by mid-2026, with births accounting for about half of this projected growth and net immigration for the other half.[34] Projections of current trends in UK fertility rates suggest that the average number of children born per woman will fall gradually to 1.84 for women born after 2000, with greater declines in Scotland compared to other UK nations.[35] The proportion of older people in the population is increasing, with the proportion of individuals in the UK aged 85 and over projected to double over the next 25 years.[34] An ageing population will place increased demands on public services, such as health and social care.

The structure of households is also changing. Ten-year trends of household composition show increases in one-person households.[36] This may lead to a rise in services aimed at single people, such as restaurants with one-person tables, similar to trends found in Japan and China.[37] However, the rise in one-person households increases the number of individuals at risk of living in social isolation, defined as an objective measure of the number of contacts a person has. Social isolation is associated with negative health behaviours (such as exercising less and smoking more), higher risk of certain medical conditions (such as heart attacks and strokes) and higher risk of death from these conditions.[38,39,40] This may result in greater demand on healthcare services. Social isolation can lead to loneliness, defined subjectively as a gap between our actual and desired social relationships. Loneliness can adversely impact on an individual's health and well-being of communities. Interventions to tackle social isolation and loneliness are likely to include technology-based schemes (such as using chatbots, virtual reality or social media to provide real or artificial companionship) and individual interventions (such as measures to enable GPs to refer patients experiencing loneliness to community activities and voluntary services, known as 'social prescribing'),[41,42,43] with the aim of reducing demand on the NHS and improving patients' quality of life. Infrastructure changes are also likely to be required, including designing age-friendly cities to enable older people at-risk of social isolation to engage in the community.[44]

An overall increase in population will require major infrastructure developments, including expansion of housing stock, transport, schools and hospitals.

Multi-family households are also becoming more prevalent, being the fastest growing type between 2007 and 2017, although they currently make up less than 2% of all households.[45] These households include older parents living with their children and grandchildren, known as multi-generational households. Other western nations, such as the USA, are showing similar trends away from single-family living arrangements to multi-generational households.[46] This trend may arise in part due to changing economic drivers. For example, younger adults are earning less than previous generations did at the same age, they have lower rates of home ownership and are more likely to have uncertain work (such as having 'zero hours' contracts, or be self-employed).[47,48,49] Multi-generational households could allow young adults with children to benefit from informal childcare arrangements and pooling of economic resources.[49]

Globally, income inequality between households has been rising over the last fifty years.[50] In the UK, inequality in household incomes has remained at a roughly similar level since the early 1990s, but is higher than during the 1960s and 1970s. Projections suggest that if government policy were to stay the same, levels of income inequality are likely to increase over the coming years into the early 2020s.[51] Greater income inequality is associated with poorer public health, leading to likely rises in demand for healthcare services.[52,53] There is also growing income inequality between older and younger people, owing to falls in the income of younger people in work and the effect of home ownership for pensioners.[54] Differences in generational preferences may also contribute to wider changes in services and political participation. For example, people aged under 25 years show lower rates of smoking and drinking alcohol than previous generations, which is likely to impact services and may lead to an increase in alcohol-free products or establishments on the high street.[55,56] Young people are also less likely to participate in formal UK politics, such as voting in elections. However, they are increasingly likely to participate in new forms of informal politics, often based on single issues and facilitated by the internet. The importance of informal politics may increase over time as they are substituting rather than complementing formal processes, and young people are likely to continue to participate informally as they grow older. However, some evidence suggests that some forms of informal participation, such as arts, culture and sports-based participation, may develop social cohesion or increase citizens' understanding of formal politics as well as their confidence to access and create change through formal processes.[57]

Implications and challenges

- An overall increase in population will require major infrastructure developments, including expansion of housing stock, transport, schools and hospitals. An ageing population will place increased demands on some services, such as health and social care.

- A rise in one-person households may require changes to infrastructure and services, either to better integrate individuals into the community or to serve their needs as single people.

- Young people are having fewer children and are more likely to be in uncertain work. These factors may require changes in the sort of housing required (with a potential rise in multi-generational households).

- Income inequality between households is increasing, which is likely to lead to increased demand for healthcare services.

- Institutions and services may need to adapt to differences in generational preferences, such as lower rates of smoking and drinking, and a tendency to engage in informal forms of politics rather than formal forms.

Key unknowns

- Population predictions are estimated using underlying assumptions about future fertility, mortality and migration. The effect of some political and economic factors (such as the UK leaving the EU) cannot be predicted.

- Social isolation and loneliness have tended to be perceived as issues affecting mainly older people, so most interventions have focused on an older population. Therefore, evidence on social isolation and loneliness in younger people is more limited.

- Predictions of how many people are in uncertain work are somewhat imprecise as they are based on the Labour Force Survey which does not include questions on the extent to which individuals rely on some types of uncertain work.

ADVANCED TECHNOLOGY IN HEALTHCARE

New technology has the potential to transform the way that health is monitored, and healthcare delivered. For example, the widespread adoption of smartphones means that health data can be monitored around the clock by an increasingly wide range of medical apps. The data captured can form the basis for personalised interventions by healthcare professionals and such systems are already in use to monitor patients with mental health problems and to provide advice on physical exercise and diet.[58] There has also been recent interest in the potential applications of artificial intelligence in medicine.[59] Such developments, combined with recent advances in medical technology, will likely have profound implications for healthcare providers, such as the NHS, as well as for patients.

Overview of area

New technologies promise to revolutionise healthcare in the coming years. Examples include:

- Applications of 3D printing in medicine. For example, this technique has already been used to manufacture slow-release drugs that cannot be made by conventional means and is also being used to make 3D clusters of cells for use in high-throughput screening to allow toxicity testing to be done at an earlier stage of the drug discovery process.[60]

- Automated language assessment combined with AI have been used to predict the onset of psychosis in high-risk youths. Researchers are now seeing whether they can apply similar approaches to other risk cohorts and other languages.[61]

- The ability of stem cells to self-organise into 3D structures that closely resemble complex organs and tissues raises the potential for the medical application of such structures in human therapy. Furthermore, researchers are looking at a range of approaches (including drugs and low-powered lasers) to coax stem cells present in the human body to regenerate and grow human tissues such as teeth.[62]

- There have been recent publications on the potential use of nanoparticles to treat dementia patients, as such particles are small enough to pass through the blood-brain barrier. Studies in mice have shown that the misshapen proteins (fibrils), the build-up of which cause Parkinson's disease, can be inhibited by nanoparticles made of graphene.[63]

- The 100,000 genomes project has provided the NHS with the infrastructure to incorporate whole-genome sequencing into areas such as the treatment of cancer and rare diseases. While the project was initially government-funded, the aim was to help kick start a UK genomics industry that will be self-supporting.

- The use of tiny robotic catheters could largely replace conventional surgery with less invasive procedures for treating blood clots, stroke and certain types of tumour.[64]

- Virtual reality technology has been used to help amputees embody their prosthetic limbs by simulating the feelings of touch when the limb contacts a surface.[65]

- New diagnostics are in development in the form of capsules that contain biosensors capable of detecting blood in the digestive system and communicate this diagnosis to a smartphone app as it travels through the patients digestive system.[66]

However, new technology also offers potential threats to healthcare systems. For example, the increasing inter-connectedness of healthcare systems with the internet of things offers multiple points of entry for cyberhackers to access sensitive medical data or to interfere with treatment regimes.[67]

Implications and challenges

- Maintaining cyber-security in the face of the increasingly interconnected and digital nature of healthcare systems.
- Regulation of new medical apps, particularly where their function is of critical importance to the well-being of patients. At present, such safety critical apps are regulated as medical devices.
- NHS funding for new technology and the changes to healthcare infrastructure that may be needed to accommodate it.
- Training of NHS staff. For example, more training will be needed so that NHS staff can use new digital systems, and GPs will also need training in emerging areas such as human genomics and counselling.
- Safety and good manufacturing practice (GMP). The emergence of 3D printing to manufacture new drugs and tissues potentially represents an outsourcing of manufacturing from large centralised facilities that are GMP-compliant to smaller facilities such as hospitals and clinics. This may compromise patient safety.

Key unknowns

- Rate of uptake of new technology into the NHS. For example, the centralised funding for the 100,000 genomes project has ended, so future genomics funding will rely on money from NHS, other grant providers and applications from industry to access the project dataset.
- Availability of sufficient staff with skills required to handle large data sets and interpret, for example, genomics data. For example, the availability of staff from EU countries is likely to fall post-Brexit, an annual review of the progress made on educating trainee health professionals has highlighted areas in need of improvement,[68] and there is a need to extend the programme to include more doctors who are not currently on formal training.
- Regulation of advanced technologies in the NHS. While the UK has regulations covering data protection, GMP and medical devices, these are currently based on EU regulation and may be subject to change post-Brexit.

- An unknown that is specific to the 100,000 genomes project is the issue of what information to report back to the participants. People enrolled into the project on an altruistic basis and were told that they were unlikely to benefit from the project as individuals. However, the bigger the dataset gets, and the more it is linked with other relevant datasets (such as medical records and health outcomes), then the more useful it potentially becomes.

Extent of the threat from hackers. While healthcare systems have been identified as being particularly vulnerable to cyber-attacks, it is not clear what the market is for information of the type that might be obtained from such sources.

CANCER TREATMENTS

For many years, the foundations of cancer treatment were surgery, chemotherapy and radiotherapy. In the past 20 years, such approaches have been joined by targeted therapies using drugs such as Gleevec® and monoclonal antibodies such as Herceptin® that attack cancer cells by targeting specific molecular changes seen primarily in those cells.[69] More recently, the focus has shifted towards cancer vaccines,[70] targeting either the viruses that cause most types of cervical cancer (human papillomavirus) or certain types of cancer cells (such as prostate cancer). The emergence of new genome sequencing technologies has given cancer researchers the tools to characterise the molecular changes to DNA and other molecules that are associated with different types of cancer. Better understanding of the molecular basis of cancer has the potential to deliver cancer treatments that are tailored to the individual patient's needs.

Overview of area

In the last few years, researchers have been developing a range of new approaches for diagnosing, characterising and treating cancers and more technologies are being mobilised to this end. The new approaches include:

- Immunotherapy. This is a type of therapy that uses T cells from the patient's own immune system to fight certain types of cancer. While there are several different approaches in early clinical trials the best results have been seen in trials using CAR T-cells to attack rare blood cancers such as acute lymphoblastic leukaemia (ALL). The patient's

T-cells are separated from their blood and genetically engineered to produce proteins called chimeric antigen receptors (CAR) on their surface. These proteins allow the T-cells to latch onto and attack the antigens displayed on the surface of tumour cells. These genetically engineered T-cells are then expanded in the lab by hundreds of millions and then infused back into the patient. T-cells displaying such CAR proteins have proved successful in treating ALL in small scale clinical trials.[71]

- Nanoparticles. Nanoparticles are tiny particles that are far smaller than the width of a human hair and tend to accumulate in tumour cells due to these cells' makeshift and leaky blood supplies. Light-emitting nanoparticles have been used to detect very small tumours to provide early diagnosis and target early cancer treatment. Modified nanoparticles that contain chlorine have also been used to treat tumours. Once they have accumulated inside a tumour, infra-red light is used to excite the chlorine molecules to produce highly reactive oxygen species that damage the tumour cells. In some patients, this process seems to kick start the body's own immune system into action to fight the cancer.[72]

- AI, machine learning and algorithms. These approaches are being used to create personalised cancer treatments, to characterise tumour progression, to better understand how cancers develop and how best to fight them, and to identify ways that cells can be modified to attack cancer cells.[73]

- New diagnostics. New diagnostic approaches include liquid biopsies that examine blood and other body samples to detect changes in DNA that might signify that the patient is in the early stages of developing cancer.[74]

Implications and challenges

The above developments could lead to improved detection and treatment of cancer as well as a better understanding of how cancers develop. However key challenges include:

- Funding for new cancer treatments. Cancer treatments are becoming more personalised, and this trend seems set to continue with the use of the new AI/machine learning and algorithms approaches to design cancer treatment plans. Similarly, new treatments such as immunotherapy are highly personalised, using modified versions of the patient's own T-cells to attack the cancer cells. Such personalised approaches tend to be among the more expensive treatments to deliver. There may be a need to change immunotherapy approaches to fit in better with the pharma industry model for bringing new treatments to market. For example, use of donor T-cells that have been engineered to avoid immunological rejection as well as to produce chimeric antigen receptors on their outer cell surface might be easier and cheaper to commercialise than bespoke treatments using the patient's own cells.

- Safety. Some patients in the clinical trials to date have shown signs of off-target effects, with the engineered CAR T-cells attacking some components of their own immune system. For example, some patients in the ALL trial showed a dramatic loss of B-cells, as these cells also produce the CD19 protein targeted by the CAR T-cells. Other potential side effects of CAR T-cell treatments include cytokine release syndrome (which can cause high fever and low blood pressure) and swelling of the brain.[75] Such side effects can usually be managed by using CAR T-cells in conjunction with other treatments.

- Extending treatments to include other types of tumour. While the new immunotherapy treatments offer hope to patients with rare types of blood cancer, they may have the potential to treat a wider range of cancers. For example, researchers are trying to use CAR T-cells against lymphoma, multiple myeloma, melanoma and various other solid tumours.[71]

Key unknowns

- Regulation of new therapies. Currently modified nanoparticle and immunotherapy treatments based on modified T-cells are regulated as advanced therapy medicinal products by the European Medicines Agency. It is unknown what regulatory route the UK will choose to follow for such treatments once it leaves the EU.

- Infrastructure. Although the UK Government has invested in the Regenerative Medicine Platform and the UK Stem Cell Bank there may be a need for more infrastructure if cell-based therapies are set to become the norm for cancer treatment. For example, the UK possesses relatively few facilities to culture large quantities of cell lines to the standards required for clinical use.

- Cost-effectiveness. As previously noted, bespoke cell-based treatments are expensive, and it is not clear that such treatments will meet the cost-effectiveness criteria for use in the NHS. To date, the treatments have been given as part of clinical trials.

- Safety. Treatments involving nanoparticles raise safety issues relating to their persistence in the human body and their impacts on other bodily systems. As cell-based treatments get more sophisticated, researchers may seek to use genome editing techniques to engineer the cells. However, some of these methods have themselves been flagged up as potentially increasing the risk of cancer.[76]

SOCIAL AND CULTURAL TRENDS

Equalising access to public services Evolving employment Future crime and justice

EQUALISING ACCESS TO PUBLIC SERVICES

Access to public services (such as healthcare, housing, education and public transport) is essential if people are to have the ability to participate fully in society.[77] Public services can also contribute to reductions in income inequality, with the largest positive effects for groups at the highest risk of poverty.[78] However, access to public services, in terms of the availability of services and their affordability, varies significantly. Access to public services varies by a range of factors, such as geographical area, ethnicity, socio-economic status, sex, age and immigration status.[77,79,80, 81,82,83] Access is particularly a problem for people facing poverty and social exclusion, which reinforces health, social, economic and political inequality.[77,84] Unequal societies tend to have a higher prevalence of poor mental and physical health, and reduced population well-being.[85,86,87,88,89] Increasing access to healthcare services and affordable, quality housing have been identified as key areas of policy concern.[84]

Overview of area

Trends over the last 50 years indicate a rise in income inequality (where earnings are unevenly divided across households) within the UK and within many other countries globally.[90,91] Projections suggest that if government policy were to stay the same, levels of income inequality in the UK would likely increase over the coming years into the early 2020s.[92] Research indicates that public services contribute to reductions in income inequality, and that the largest positive effects are on populations at higher risk of poverty.[78]

In terms of access to healthcare, some groups are less able to access health services than others, which can lead to poorer levels of health. This includes Roma and Traveller communities, as well as migrants, asylum seekers and homeless people.[84,93,94] Other groups are less likely to take up health services available to them. For example, men, young people and individuals from ethnic minority backgrounds are less likely to attend NHS health checks, while those aged under 30 or over 90 years old, and those from socioeconomically disadvantaged backgrounds are more likely to miss multiple GP appointments.[81,82] Some groups also receive lower provision of some health services, such as hip and knee replacement and cardiac surgery; for example, research shows that women and individuals living in areas of deprivation are less likely to receive necessary hip replacements than other groups.[95] Individuals from ethnic minority backgrounds also report less positive experiences of care in patient surveys compared with other groups.[96] Variation in experience of care and unequal access to, or uptake of, healthcare services can exacerbate health inequalities arising from some demographic groups being at greater risk of certain health conditions.[97] Public bodies (including healthcare services) have a legal duty to reduce inequalities. There are various ways in which they carry out this duty. For example, NHS England has allocated funding to local areas to reduce regional inequalities.[98] To address some forms of health inequality (such as those due to age, sex or ethnicity), prevention and treatment measures may need to be better targeted to specific groups in the future to ensure that appropriate healthcare services are available for, and taken up by, different populations.[99]

Disparities in access to healthcare among different demographic groups can be compounded by regional differences in health outcomes. For example, living in a geographical area of higher deprivation is consistently linked to poorer health behaviours (such as increased risk of smoking and physical inactivity), poorer health outcomes, fewer years living in self-assessed 'good health' and lower life expectancy.[100] Children growing up in areas of deprivation are at higher risk of childhood obesity, childhood injury (such as poisonings, fractures and burns) and infant mortality.[101,102] The gap between the richest and poorest in society for some outcomes (such as infant mortality, child obesity and female life expectancy) is growing.[103,100] Demand for healthcare and social care is forecast to grow in the future because of population growth and an increase in the prevalence of long-term health conditions (such as diabetes and dementia).[104] Greater income inequality is also associated with poorer public health.[86] Projected increases in income inequality are likely to compound demand pressures caused by population changes, especially in geographical areas of deprivation.[105] Unequal geographical distribution of healthcare services may further exacerbate inequalities. For example, centralisation of services may reduce provision of healthcare services in rural areas, and access may be further hindered by weak public transportation systems, putting extra travelling costs on people already experiencing poverty and social exclusion.[106]

Some groups are less able to access health services than others, and other groups are less likely to take up health services.

In terms of access to affordable, quality housing, there are disparities between different demographic groups. For example, analysis of figures on housing occupancy from 2014–2017 show that 3% of households in England were overcrowded,[107] and that individuals from minority ethnic backgrounds are more likely to live in overcrowded homes than those of White British background,[107] a trend that has been increasing since 2001.[108] People from minority ethnic backgrounds also spend, on average, a higher proportion of their income on rent but are more likely to live in lower quality housing.[109] Poor quality and overcrowded housing is associated with poorer physical and mental health.[110]

There has also been a significant increase in homelessness in all its forms in recent years, which, at present, costs the public sector over £1 billion a year.[111] Some groups are at greater risk of homelessness, such as recent care leavers and single parents.[112,113] Homeless and vulnerably housed people experience a high proportion of physical and mental health concerns compared with the general population, and it has been estimated that homeless people use acute hospital services at about four times the rate of the general population.[114] Mental and physical health problems can be both a cause and a symptom of homelessness. Homeless people face additional challenges in accessing other public services (such as healthcare), and evidence suggests that people in such living situations would benefit from tailored services that are intended to meet their specific needs. Some estimates suggest that targeted approaches to prevent homelessness could also be more cost-effective than providing services to alleviate the outcomes of homelessness.[115]

One aspect of increasing access to suitable housing in general is to address issues with under-supply of housing. However, building of new homes is not meeting current demands, and figures suggest that upwards of 240,000 homes would need to be constructed annually to meet the housing needs of a growing population.[116] At the same time, however, affordability of housing in both the private and social housing sectors would need to be addressed.[117,118] Additional measures to prevent discrimination of particular groups, such as migrants, would also need to be addressed to increase equal access.[119] There are also long-term concerns about the security of housing from the effects of climate change, such as flooding. Deprived communities may be at greater risk of damage to housing from these factors because they are less likely to make adjustments to their property to increase its resilience.[120]

Implications and challenges

- Income inequality is projected to rise in the future and may lead to a greater demand for healthcare services among some demographic groups and in more deprived areas. Public services can contribute to reducing income inequality; however, unequal access can compound health, social and economic inequality.

- Some groups are less able to access health services than others, and other groups are less likely to take up health services, which can exacerbate health inequalities arising from some demographic groups being at greater risk of certain health conditions.

- Disparities in access to healthcare among different demographic groups can be compounded by regional differences in health outcomes and in unequal geographical distribution of healthcare services.

- Better targeting of healthcare services to specific groups may address some forms of unequal access and mitigate health inequalities; however, changes to healthcare services alone is unlikely to eliminate health inequalities as they are related to local deprivation and income inequality.

- Access to suitable, quality housing is unequal, with a significant rise in the number of people at-risk of homelessness, or living in poor quality or unsuitable accommodation.

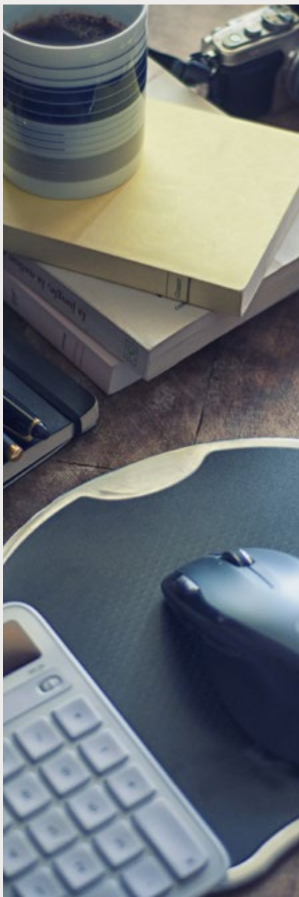
- Increasing access to quality housing more equally will require addressing issues with under-supply and affordability, as well as implementing measures to prevent discrimination of particular groups.

Key unknowns

- Projections of income inequality have underlying assumptions and cannot account for all possible future changes in policy or global trends.

- Research into understanding health inequalities (where some groups are more at risk of certain conditions) is ongoing. Access to health services is likely to account for only part of the underlying causes of health inequalities.

EVOLVING EMPLOYMENT



Developments in technology are driving change in the nature and structure of work and employment. Employees express concern that continued automation in the workplace is likely to affect a wide variety of jobs currently undertaken by humans, including high-paying jobs in the service sector.[121] Estimates of the number of current roles that could be automated vary by country, but research suggests that up to 35% of UK jobs are at risk of automation.[122] As well as replacing roles traditionally carried out by humans, technology is also likely to play a greater role in monitoring human workers and ensuring workplace safety. For example, wearable technology can be used to monitor the stress levels of workers and drones may be used to assess hazardous work environments.[123,124] The internet and web-based platforms are also changing the structure of employment, with more people working in flexible employment as opposed to in long-term permanent roles.[125] This is likely to lead to changes in taxation, trade union membership and employment law.[126,127,128] At the same time, there are continued pay differences associated with gender, ethnicity, socio-economic status and geographical region.[129,130,131] For example, although the gender pay gap has reduced over the last 20 years, it persists across both the public and private sectors.[132,133,134] New reporting obligations on organisations and predicted economic benefits may contribute to a shift towards reducing gender-based income inequality in the future.[135]

Overview of area

The rise of new technologies, such as smart technology and artificial intelligence, will change the future workforce. Research suggests that these technologies are replacing human work, both in low-skilled positions and in high-paying jobs that had previously been considered more resistant to automation, including those in customer service, transport, healthcare and education.[121,122] Researchers argue that many skills once considered essential in professional occupations (such as empathy or judgement) may not need to be replicated by new technology for it to be just as effective at delivering desired outcomes.[136] For example, a recent study found that participants in a simple task performed better when supervised by an unempathetic robot than a kind and empathetic one.[137] Estimates for how many jobs are likely to be automated vary, with some estimates suggesting up to 35% of current roles in the UK will not be undertaken by humans in the future.[122] The likelihood of roles being automated depends on the skills involved. Some researchers suggest that increased automation could lead to an increase in income inequality, with technology predominantly replacing middle-income roles, and could increase gender inequality in the workforce.[122,138] However, other research suggests that technology can boost productivity and increase the number of jobs.[139] Technology may also have a role in workplace monitoring and safety in the future. For example, drones are currently being used to assess hazardous work locations before deployment of human workers[123] Other potential uses of technology include testing new workspace layouts through virtual reality to find out in which environments workers are the happiest and most productive.[140] The use of monitoring technology in the workplace is also likely to rise. For example, future employers could monitor heart rate, eye movements and facial expressions to assess the stress and attention of workers to ensure their decision-making is not impaired.[124] The corporation Walmart has also patented monitoring technology that can record audio data at checkouts to assess employee performance and productivity.[141] Research that has tracked previous adoption of technology in the workplace has shown that it can increase work intensity and working time for employees, which can be detrimental to health and well-being.[142,143]

Projected increases in the number of people in flexible employment is likely to require changes to taxation and employment law.

With changes in the traditional workforce driven by new technologies, some researchers predict that working in flexible employment, such as being self-employed or working in the gig economy (where money is earned doing flexible short-term jobs), will be the norm in the future.[144] Research conducted for a review on the gig economy by the government found that roughly 4% of the population of Great Britain worked in the gig economy between 2016 and 2017, with much higher levels in London.[145] Currently, the majority of workers in the gig economy have other employment.[125] However, in the future there may be more workers in the gig economy and more workers for whom pay from the gig economy is their sole income. Research suggests that precarious work, such as that found in some types of flexible employment, is linked with lower physical and mental health, as well as lower overall well-being.[146] Evidence also suggests that growth in the gig economy may suppress workers' wages, with a negative correlation found between workers in the gig economy and wage inflation.[147] Globally, stakeholders have also raised concerns over how workers in the gig economy access workplace benefits, such as social insurance, sick leave and pensions.[148,149] Some new companies are emerging globally that allow workers to access these benefits by paying a percentage of their flexible employment wages to a separate private company that then administers benefits.[150] However, it is unclear to what extent these companies will be able to address concerns over reduced benefits.

Higher rates of self-employment may see further declines in trade union membership.

These changes are likely to have implications for trade unions and regulatory bodies. Trade union membership has declined substantially since a peak in 1979 and in 2017 just 23.2% of UK workers were members of a trade union.[151] The rate of trade union membership is likely to fall further with growth in self-employment and the gig economy. Historically, higher trade union membership has been associated with greater social solidarity and greater collective wage bargaining powers.[152,153] However, new means of collective bargaining may emerge from the decline in trade union membership, including a greater use of community organising and cross-country social movements.[128,154] Alternatives to trade unions for self-employed individuals may also become more prevalent, combining workplace benefits, campaigning and networking opportunities. Changes to taxation and employment law are likely to be needed to respond to these developments in the workforce.[126,127]

There is also likely to be increased interest in how income from employment is distributed across the population. Trends over the last 50 years indicate a rise in income inequality within many countries globally.[155,156] Projections suggest that if government policy were to stay the same, levels of income inequality in the UK are likely to increase over the coming years into the early 2020s.[155,156,157] Current estimates suggest continued pay differences associated with gender, ethnicity, socio-economic status and geographical region.[129,130,131] For example, the mean pay varies across different ethnic groups, with workers from Pakistani, Bangladeshi and Black backgrounds (both those born in the UK and abroad) earning on average less per hour than all other groups.[158,159] The gender pay gap is also likely to receive continued policy focus, although this may be more on how it varies between different groups of women. Although the gender pay gap in the UK has reduced in the last 20 years,[160] it still persists across the vast majority of organisations in the public and private sector[132,133,134,161] and is wider than the OECD average.[162] The World Economic Forum estimates that if gender pay parity were achieved in the UK, it could create additional GDP of around £155bn.[135] Additionally, evidence indicates that greater involvement of women in higher positions within organisations is associated with reductions in other forms of social inequality.[135,163] New obligations on organisations to report on gender pay gaps and predicted economic benefits of gender pay parity are likely to put focus on reducing gender-based income inequality in the near future, and may also lead to calls for reporting on other pay gaps (such as by ethnicity).[161] Suggestions of how to close the gender pay gap include changes in recruitment, retention, training, flexible working and employee benefits.[164,165]

Implications and challenges

- Increased automation replacing human labour in both low-skilled and professional occupations is likely to have wide-ranging impacts on society and the economy, although the exact effect it will have on the number of jobs and future pay is unknown.

- The use of technology to monitor workers and workplaces may create a safer environment for workers, including reducing the risk of injury or death in hazardous situations (such as those faced by emergency aid workers, police or the armed forces) but also raise issues around privacy and security.

- Projected increases in the number of people in flexible employment is likely to require changes to taxation and employment law to ensure that workers have access to, and contribute to, the public services that they require.

- Higher rates of self-employment may see further declines in trade union membership, but this may be replaced by new forms of collective bargaining, community organising and campaigning.

- The obligation to report the gender pay gap may see an increase in organisational and national polices to promote gender pay parity and may lead to calls for mandatory reporting of other pay gaps, such as for different ethnic groups or people with disabilities.

Key unknowns

- It is not clear how many jobs or which roles are likely to be automated in the future, or what the impact on displaced workers might be, because there are unknown factors about how roles may develop.
- The use of different technologies in the workplace is speculative and may not be adopted in the future, either because they are not approved for use or because they are not used by employers for other reasons (such as staff hostility or economic viability).
- The impact on health and well-being of the increase of technologies in the workplace is not yet known and this could have potential effects on healthcare systems.
- It is difficult to estimate the number of workers who will be in flexible employment in the future because there are many potential factors that can influence estimates.
- Data on pay gaps are limited, although recent obligations to report on gender pay gaps have created more data than was previously available. There are no current obligations to report on other pay gaps (such as ethnicity) so it is difficult to source data to track these
- Modelling of the estimated economic and social benefits of narrowing the gender pay gap contains assumptions that may differ from actual effects.

FUTURE CRIME AND JUSTICE

Increased use of technologies in policing, such as robotics and artificial intelligence, is likely to change the way crimes are committed, detected and handled in the future.[166,167,168] For example, there may be greater use of predictive policing, where algorithms are used to assess how likely an individual is to engage in criminal behaviour.[169,170] Trends in prison populations indicate that the number of UK prisoners is likely to rise over the next 5 years and that there will be a greater increase in prisoners aged over 50 years compared with other age groups.[171,172] This demographic change is likely to require alterations in prison facilities and in sentencing to prevent overcrowding. These alterations could include greater use of non-custodial sentences.[173,174,175] As well as changes in sentencing, trends indicate developments in rehabilitation and crime prevention. Future strategies in this area may take a ‘whole system’ or ‘public health approach’, where multiple agencies are involved in programmes to reduce the spread of criminal behaviour.[176,177,178]

Overview of area

Over the next few decades, there is likely to be a rise in the use of new technologies in how crimes are committed, including trading illegal substances, stalking or harassment, impersonating individuals, hacking, fraud and other cybercrimes (see New Directions in Cyber Security).[179] New technologies are also likely to lead to changes in how crimes are policed and sentenced. Trends indicate greater use of robots and advanced motion detection technology to monitor potential crimes.[165,166,167] Some courts are already using technology such as virtual or video-conference hearings; however, there are criticisms that this reduces the transparency of the justice system and has implications for data protection.[180] There is also likely to be a rise in the use of artificial intelligence, machine learning, predictive algorithms and facial recognition software in the policing and prosecuting of crimes.[168] For example, algorithms can be used to predict how likely an individual accused of criminal behaviour is to attend court or reoffend and facial recognition software can be used to detect whether an individual is likely to be lying.[168] However, there are concerns that the use of algorithms may introduce or extend racial bias, with evidence showing that an algorithm used to predict reoffending rates overestimated the risk for black individuals compared with white individuals.[181] There are pre-existing racial biases in the police and criminal justice system in the UK. For example, Black, Asian and Minority Ethnic (BAME) individuals are more likely to be subject to a stop and search by the police than white individuals, are more likely to be found guilty in court, and are more likely to receive longer than average sentences.[182,183] If arrest or conviction data are used in algorithms, they may perpetuate or increase this bias. However, other forms of data that have been shown to contain less bias (such as victim survey data) could also be used to develop algorithms. When carefully designed and tested, algorithms are capable of being less biased than humans in decision-making.[184]

The accuracy of algorithms in predicting future criminal behaviour can be undermined by underlying biases, incorrect assumptions and technological problems.

As well as developments in the way crimes are detected and prosecuted, there are emerging trends in sentencing and rehabilitation. Trends since 2002 indicate that the UK prison population is ageing, with numbers of individuals in older age groups growing fastest; 16% of the current prison population is aged over 50 years and this is predicted to rise.[171] An older prison population will likely require adaptations to the prison environment, including alterations for disability and mobility needs, greater access to physical and mental healthcare, and provision of suitable end-of-life and palliative care.[171,172,185] The prison population in the UK currently stands at around 92,500, with 58% of prisons being reported as overcrowded.[171] The prison population is predicted to rise to 98,000 by 2022.[171] Future overcrowding in prisons may initiate trials of non-custodial sentences or shortened sentences, which could increase the use of other post-conviction penalties such as community service or electronic tagging.[172,174] Trends in other countries include increasing prison labour to meet the funding demands of growing prisons.[172,186,187] Suggestions for future prisons also include locating them nearer communities, reducing their size and focusing more on rehabilitation.[173]

Trends also indicate a growth in community-based rehabilitation and crime prevention that takes a 'whole system' or 'public health approach' where multiple agencies (such as police, mental healthcare providers, educators and social care services) are involved in programmes to reduce the spread of criminal behaviour.[176,177,178] For example, trials of initiatives to prevent future offending in Chicago include school-based programmes aimed at reducing youth violence, which work alongside other initiatives to alleviate poverty and improve health.[188] There have also been trends towards policy interventions that attempt to change behaviour around activities related to criminal behaviour (such as regulations around alcohol trading times) in order to reduce crime.[189,190]

Implications and challenges

- Monitoring devices, such as body-worn cameras or camera-equipped robots, may be at risk from hackers who can access and alter video evidence of crimes.[191] Ensuring that these new technologies are used appropriately and are resistant to criminal attacks are key challenges.

- The accuracy of algorithms in predicting future criminal behaviour can be undermined by underlying biases, incorrect assumptions and technological problems.[192,193,194] Making algorithms that are accurate, unbiased and open to scrutiny will be an important challenge for predictive policing.

- Overcrowding in prison and the ageing of the prison population is likely to present practical and financial challenges.

- Although prison labour has been suggested as a means to offset the running costs of prisons, research suggests that it is disproportionately carried out by those from ethnic minorities and from lower socioeconomic backgrounds.[186] Whether prison labour can be used ethically and without discrimination will need to be considered by prison services.

- Community-based rehabilitation and prevention requires large-scale infrastructure change and inter-agency working, which may present financial and organisational challenges.

Key unknowns

- Current uptake of new technology may not translate into greater use of this technology in the future. Public support and positive evaluations may be required to embed its use in day-to-day policing.

- Offender profiling is currently not consistently evaluated, and predictive policing about future offending by individuals can be based on these unassessed assumptions.[195]

- Predictions for the prison population are an estimate based on underlying assumptions. The actual future population could be very different from predictions, especially as they cannot account for unpredictable future changes (for example, changes to sentencing minimums, use of short-term sentences or changes in types or prevalence of crime).[171,196]

- Evidence around approaches to reduce reoffending is growing.[197] This indicates that not all interventions to reduce reoffending are equally successful and some may have no effect or a negative effect on reoffending.[198,199]

- There is evidence that some types of public health approaches can reduce crime in a local area in the short-term.[200,201] However, assessing long-term impact and effects of large-scale projects encompassing multiple agencies can be difficult.[200]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GEOPOLITICAL AND GOVERNANCE CHALLENGES

Shifting energy governance New frontiers in defence technologies New directions in cyber security Science, communication and behaviour

SHIFTING ENERGY GOVERNANCE

The actors, institutions and processes that govern energy resources are evolving. Conventionally, central governments have set policy and designed markets in order to meet objectives around energy security, affordability and greenhouse gas emissions reduction ('decarbonisation'), but there is often competition between these and other policy goals. For a number of reasons, the roles of sub-national state and non-state actors are evolving and, in some respects, increasing. Subnational government bodies, financial institutions, NGOs and multinational firms all possess influence over energy policy, and their own objectives and agendas may not necessarily align with one another or with central governments. This may lead to inefficient policy outcomes in the future (or the most appropriate policies being restricted in certain areas) and challenges in decarbonising the global economy.

Overview of area

Energy governance is the process of organising the use, control and trade of energy, and the associated resources that underpin economic activity. It encompasses the actors involved in decision-making (from the global to local level), the systems that underpin them (from trade systems to power networks) and the related processes (e.g. market exchange) that facilitate their operation. Moreover, it includes the public and private institutions that design and implement these markets, sets their parameters and defines their goals.[202] UK energy governance has evolved substantially in the last half century;[202,203] from a state-led framework with nationalised bodies in the mid-20th century, through privatisation and market liberalisation, and returning again to a greater level of state influence. Most recently, sub-national bodies, such as local authorities, are increasingly taking responsibility for local energy systems and sustainability plans. Recent developments are the result of the growing recognition of the need to reduce UK greenhouse gas emissions to mitigate climate change.[204] Today, activity in UK energy markets takes places via private financing that is enabled by a framework of public policies designed to promote investment.

Within the current context, energy and climate policy is broadly set at the level of central government and framed at the European level. However, policy tensions can exist within governments, and there are multiple other actors – intergovernmental organisations, NGOs, multilateral finance institutions, regional actors (such as energy hubs) and local authorities – with energy governance capabilities whose influence is evolving and arguably increasing. EU energy and climate legislation affects UK product efficiency and renewable power targets; the GB energy system is physically connected to, and currently operates within, the regulatory framework of the EU Internal Energy Market; and EU State Aid rules affect major UK energy infrastructure project development and energy market operation.[205,206,207,208,209,210] The US is experiencing increased climate ambition at the State or city level in reaction to the current administration's rolling back of federal climate policies.[211,212,213] Unilateral climate change measures by 'sustainable cities' are facilitated by NGOs, such as the C40 Cities Climate Leadership Group.[214,215] New business and ownership models are being explored by community energy groups, with assistance from local authorities and regional energy hubs.[216] This plurality of governance actors may lead to tensions between their respective priorities, given their competing political, economic and social interests that span dimensions outside of the energy and climate sphere. In addition, there is growing recognition that climate policy will have an increasingly disruptive effect on workers in some industries (such as agriculture, or oil and gas) and on many aspects of consumer lifestyles. This has increased interest in 'just transition' discourse,[217,218] as well as broader public engagement in climate policy. Deliberative democracy tools, such as mini-publics and citizens' assemblies, are increasingly being used to gain insights into the perspectives and wishes of an informed public.[219]

Local governance actors are taking an increasing role in the UK energy system.

There is a risk that the competing drivers of energy and climate policy can act to counteract or offset one another. Although this phenomenon is not new, it may be accelerated as new technological and political opportunities and challenges arise in the coming decades. A rapidly growing proportion of UK electricity is generated from renewable sources, such as rooftop solar panels and wind. Many of these technologies are smaller in scale and more geographically disperse than conventional (fossil-fuelled) power generators and lend themselves to new forms of governance, such as through household or community ownership.[220] On the other hand, large incumbent actors, such as multinational firms whose current business model depends upon selling fossil fuels, could possess significant influence over the transition to a more sustainable energy and resource system as they adjust to a new landscape in which action on climate change mitigation is accelerating.[221]

Implications and challenges

- The success of national energy and climate change policies' objectives may be diminished by competition from other policy goals.[222] For example, ambitions to reduce energy costs may, in the short-term, favour higher-polluting forms of energy, as may the desire to "keep the lights on".[223] These tensions also exist within government itself – for example, tax relief for oil and gas extraction explicitly aims to maximise fossil fuel production for economic benefit, and transport policy seeks to phase out fossil-fuelled vehicles while simultaneously promoting airport expansion. It is unclear the extent to which these competing aims may prevent progress in decarbonising the energy sector and wider economy.

- The interests of non-state actors (e.g. intergovernmental organisations, NGOs, multilateral financial institutions and industry) can misalign with each other and work to restrict progress in achieving energy policy objectives.[224,225,226,227,228] Their priorities may even explicitly counteract those of state actors.[229]

- Local governance actors are taking an increasing role in the UK energy system, and it is frequently argued that cities and local authorities may be better placed to co-promote decarbonisation alongside local economic development.[228,230,231] However, local authority resource constraints can act a barrier to engagement with the energy system.[232]

- Devolution to UK nations can lead to policy divergence across the UK – for example in the onshore planning regime – which can lead to non-uniform deployment across nations.[233,234]

- Geopolitical tensions could result in the production and trade of energy and mineral resources becoming weaponised, threatening trade balances and energy security.[235,236,237]

- Climate change, resource scarcity and related environmental pressures present complex systemic risks which are characterised by non-linearity (e.g. by the presence of 'tipping points') and intractability. Conventional political institutions and risk management approaches are unsuited to addressing risks of this kind,[238] having evolved to manage conventional risks that can be easily identified and isolated. It may be that new governance mechanisms, actors or processes are necessary to mitigate these risks at the subnational, national and international level.[239]

Key unknowns

- The UK's future relationship with the European Union on matters such as trading arrangements, market integration and regulatory alignment will affect the extent to which UK energy governance is bound by EU regulations and directives.[208] Political objectives around issues such as freedom of movement and the jurisdiction of the European Court of Justice will indirectly influence the shape of energy-specific arrangements, for example, the UK's continued participation in the EU Internal Energy Market and Emissions Trading Scheme.[207]

NEW FRONTIERS IN DEFENCE TECHNOLOGIES

The potential for military engagement to occur in non-traditional domains such as cyberspace and outer space is increasing, as countries and non-state actors develop their military capabilities in these spheres. Developments in technologies capable of disrupting, damaging or deceiving the systems operating in these environments may increase the risk to UK systems and infrastructure from hostile actors. The spread of misinformation and hyper-partisan views online has raised concerns about the weaponisation of information, with potential consequences for democratic institutions. Technological innovations in the more traditional military domains of land, sea and air may also lead to the disruption of existing defence systems and infrastructure.

Overview of area

The potential for conflict to occur in arenas beyond the traditional domains of land, sea and air, is increasing. A growing number of countries are looking to use both cyberspace and outer space[240] to enhance their military capabilities and their national security.[241,242] In 2018, the UK Government announced the launch of a Defence Space Strategy that aims to ensure the UK has the capabilities and skills to protect its assets in outer space,[243] while continuing to develop the UK's defensive and offensive capabilities under the National Cyber Security Strategy.[244,245] The US, China[246] and Russia are among other countries seeking to expand their military capabilities in cyberspace and outer space. The US Government, for instance, set out plans last year to establish a US Space Command to integrate space capabilities across all branches of the military.[247]

As cyberspace and outer space become increasingly significant for national security, it is likely that interest will increase in developing technologies that can be used to disrupt, damage or deceive the systems operating in these domains.[248] Several countries, including the US, China and Russia, have demonstrated that they have the military capability to carry out a range of attacks on satellites, using weapons such as ballistic missiles, signal jammers and high-powered lasers.[249,250] In cyberspace, the Head of the UK National Cyber Security Centre (NCSC) has said that the majority of the incidents dealt with by the centre since it became operational in 2016 were undertaken by groups directed, sponsored or tolerated by governments of nation states in some way hostile to the UK.[251] In October 2018, the NCSC identified that the Russian military intelligence service (the GRU) was almost certainly responsible for a number of cyber-attacks around the world,[252] including an attempt to gain access to the UK Defence and Science Technology Laboratory computer systems.[253] Furthermore, concerns have


Avon Protection

been raised about the potential for the spread of misinformation online to undermine the integrity of democratic institutions in the UK.[254] For example, the Prime Minister has accused Russia of interfering in elections and planting 'fake news' in an attempt to 'weaponise information' and sow discord in the West.[255] 'Hybrid warfare', which involves the coordinated use of both military (force) and non-military approaches (such as political, economic or information manipulation) is not new, however advances in information and communication technologies have created new avenues for targeting societies and political systems.[256,257]

Within more traditional military domains, technological developments are leading to innovations in weaponry and other military equipment in the UK and abroad. The Ministry of Defence's research portfolio spans numerous areas, including sensor technologies, novel materials, communications, chemical and biological warfare defence, quantum technologies, and data science.[258] For instance, in 2018, the British Army conducted 'Exercise Autonomous Warrior' on Salisbury Plain, a month-long trial of over 70 robotic and autonomous systems to identify technologies to support soldiers on the battlefield.[259,260] Innovations in human enhancement technologies may provide operational advantages by enabling soldiers to recover more quickly from injury and illness, or to avoid them completely.[261] The US Defense Advanced Research Projects Agency is developing 'smart bandages' to track and stimulate the process of wound healing, implants that monitor soldiers' physiology to detect disease or illness, and technologies that deliver treatments for conditions such as pain, general inflammation and anxiety, by modulating a soldier's nervous system.[262,263,264] Meanwhile, technology advancements made by other nations may raise challenges for the effectiveness of the UK's defence capabilities. For example, a Chinese military electronics company, Electronics Technology Group Corporation, has announced that it is developing a quantum radar system that uses entangled photons (particles of light that have been intrinsically related, see POSTnote 552) to detect objects.[265,266] Stealth aircraft that have been designed to elude conventional radar could be much more susceptible to detection by such a system, however critics have questioned whether reports have overstated how far advanced development of this system actually is.[267]

Recruiting and retaining staff is a challenge for the UK's armed forces and security agencies.

Implications and challenges

- The UK and other nations are becoming increasingly dependent on infrastructure based in both cyberspace and outer space.[268]

- Agreeing how existing international law applies to military activities in cyberspace and outer space is a challenge for nation states. Projects such as the Tallinn Manual, in which legal experts provided their views on how international law applies to cyberwarfare, have attempted to address this.[269]

- The use of new technologies, such as AI, in military operations presents challenges for transparency, accountability and humanitarian protection.[270]

- Developing the UK's defence capability requires people with a wide range of skills.[271] Recruiting and retaining staff is a challenge for the UK's armed forces and security agencies.[272]

- Although propaganda and misinformation are established phenomena that pre-date digital technologies, the internet presents new opportunities for creating, spreading and targeting content more rapidly than before.[273]

- The adoption of new technologies that are connected to networks can provide new capabilities but also introduces cyber security risks that may make them vulnerable to attack.[274]

Key unknowns

- It is often difficult to ascertain the true extent to which military technologies have been developed, given the highly classified nature of the research and the potential for government and industry to benefit from exaggerating or understating their capabilities in a particular area.

- It can be hard to attribute the source of cyber-attacks because attacks often take complex routes around the internet, sometimes via previously infected devices, to mask their origin. This contributes to the challenges the UK has in achieving targeted, proportionate cyber deterrence.

- It is difficult to predict who will decide to use autonomous systems (such as weapons systems) in the future. Users may include both state and non-state actors, such as terrorist groups.[275] Development and adoption may depend on a number of factors such as economics, legal constraints, public opinion, societal values, technological challenges, and governance (e.g. whether a state is democratic or autocratic).[276,277,278]

- The full implications of using automation technologies in military operations are not well-understood and research in this area is not extensive.[279]

NEW DIRECTIONS IN CYBER SECURITY

The internet and the devices connected to it have important social and economic benefits, however cyber-attacks are growing more frequent and sophisticated, and are more damaging when they succeed.[280] Predicted trends in cyber-attacks include an increase in the use of cryptojacking against visitors to websites, greater use of supply chain compromise to introduce vulnerabilities into digital products and services before they reach consumers, and greater targeting of hardware vulnerabilities. Increasing adoption of 'the Internet of Things' is creating new challenges for cyber security and is likely to drive the creation and exploitation of more cyber security vulnerabilities. Artificial intelligence (AI) is also likely to be increasingly used, both to facilitate cybercrime and to counter it.

Overview of area

The UK has the highest levels of internet use in the G7,[281] with a greater percentage of people shopping online than in any EU country.[282] Rates of cyber-dependent crime and cyber-related fraud now make up one-third of all crime in the UK.[283] Major cyber incidents in 2017–2018 included those involving ransomware (software that encrypts files and demands a ransom for making them usable again); distributed denial of service (DDoS) attacks, which can block access to websites and internet-connected services by flooding them with requests for data; and data breaches.[284] Notable data breaches reported in 2018 included those disclosed by British Airways,[285] Facebook[286] and Reddit.[287]

The National Cyber Security Centre (NCSC) has predicted that future trends in cyber-attacks are likely to include an increase in the use of 'cryptojacking', which involves installing software onto a user's computer to mine cryptocurrency without their knowledge.[288,289] The NCSC also anticipates future cyber security incidents caused by supply chain compromise, which typically involves criminals introducing security vulnerabilities or other exploitable features into equipment, hardware, software or services before they are supplied to customers. IBM has highlighted cyber security risks inadvertently created by staff within organisations, for example when they fall for email scams or improperly configure systems, services or devices.[290] The FBI estimates that from October 2013 to May 2018, US$12.5 billion was lost globally to 'business email compromise', which usually involves using social engineering or computer intrusion techniques to compromise company email accounts and conduct unauthorised transfers of funds.[291]

The number of software vulnerabilities that have been publicly disclosed has increased significantly in recent years. According to IBM, over 42,000 vulnerabilities have been reported in the past 3 years, accounting for 30%

of all publicly reported vulnerabilities since 1988.[292] In 2018, several new hardware design flaws were found in processors used in most personal computers and mobile devices.[293,294,295] These vulnerabilities (known as Spectre, Meltdown and Foreshadow) can be exploited to gain unauthorised access to security-critical data. Although there is little evidence to date of these vulnerabilities being used maliciously, they raise the possibility of hardware vulnerabilities being targeted in future cyber-attacks. Vulnerabilities in firmware (software produced by hardware manufactures to control a hardware component or system) have also been identified and used in cyber-attacks.[296,297] Attacks that exploit these types of vulnerabilities can be particularly difficult to detect and stop, and may become increasingly common in the future.

A successful cyber-attack on an autonomous vehicle or an implanted medical device might result in physical harm or possible loss of life.

Technological development is helping to drive the creation and exploitation of cyber security vulnerabilities. Increasing numbers of devices, from toys to washing machines, are being connected to networks such as the internet. This 'Internet of Things' presents new opportunities for social and economic benefit, while creating challenges for cyber security.[298] Insecure devices can compromise privacy and security, may be hijacked to distribute malware or unwanted emails, and can be used collectively to disrupt others' use of the internet.[299] For example a device might be recruited into an automated network of compromised devices and used to launch a DDoS attack by flooding websites and internet platforms with requests for data, rendering them inaccessible. In April 2018, an international law enforcement operation involving the National Crime Agency shut down Webstresser.org, a website providing a DDoS-for-hire service, which Europol says was the source of over 4 million DDoS attacks, with over 136,000 registered users.[300] According to the NCSC, criminals are only just beginning to explore ways of generating income from attacking the Internet of Things, and most current approaches focus on DDoS attacks.[301] Cyber security analysts have predicted that increasing numbers of devices will become compromised, and that large-scale attacks are likely to take place.[302] To help address poor cyber security standards, the UK Government has produced a voluntary Code of Practice for the development, manufacturing and retail of connected consumer devices.[303] The Code aims to encourage a "secure by design" approach to reduce the burden on consumers ensuring that their devices are secure. The Government is also considering a labelling scheme to help inform consumers.

AI is also shaping the cyber security landscape. AI has the potential to be used both as a tool to facilitate cybercrime and to counter it. It might be used by human attackers to increase the efficiency and scale of their attacks, as well as by malicious software (malware) to acquire contextual understanding that could enable it to evade detection and maximise the damage it causes.[304] Other possibilities include AI being used by criminals to automatically compose fraudulent emails that replicate the tone and style of a person known to the recipient, or to analyse and mimic a user's speech and linguistic traits, opening up numerous possibilities for identity fraud.[305] There is also significant potential for AI to be used in cyber security, for example by using it to spot cyber-attacks more effectively,[306] or to detect software vulnerabilities and automatically install the appropriate software patch.[307] AI approaches might also be used to develop digital forensics tools to aid security researchers trying to find out who created a particular piece of malware. For example, researchers at George Washington University have demonstrated that machine learning algorithms can be used to analyse samples of computer code and match them to the people who wrote them.[308]

Implications and challenges

- Cyber-attacks can affect both organisations and individuals and can lead to economic losses, infringements of privacy, disruption to essential services, and may put physical safety and security at risk.[309,310]

- As more safety-critical devices become connected to networks such as the internet, the potential consequences of cyber-attacks may become more severe. For example, a successful cyber-attack on an autonomous vehicle or an implanted medical device might result in physical harm or possible loss of life.[311,312]

- Challenges to improving cyber security include the complexity of supply chains, difficulties assessing security, and a shortage of cyber security knowledge and skills.[313]

- Consumer surveys by the cyber security industry report that poor cyber security practices, such as not changing default passwords, are common.[314,315] Focus groups suggest that consumers may underestimate the risk and severity of cybercrime that targets devices and believe that security is not their responsibility.[316]

- Cyber security guidance for consumers is often complex and inconsistent. Consumers often need technical knowledge in order to assess the cyber security of a device and to set it up securely, which they may not have.[317,318] The NCSC is working to address this by producing publicly available cyber security guidance.[319]

- The rapid pace of technological change and continuous innovation by criminals seeking to exploit vulnerabilities can leave cyber security experts and digital forensic practitioners playing catch-up.[320]

Key unknowns

- It is not clear what new vulnerabilities will be discovered in the future and how severe an impact they will have. It is common for vulnerabilities to be discovered after a product or service is already in use, so it is possible that widely used systems may have as yet undiscovered vulnerabilities.

- There is currently debate among stakeholders about the effectiveness of mandatory standards or labelling schemes for internet-connected consumer devices, as well as the adequacy of product safety, liability and consumer rights laws.[321]

- It is unclear to what extent leaving the EU will affect the UK's ability to cooperate with other countries on cyber security cooperation. The Government has said that it wants to continue to share information about cyber threats and work with Europol and the European Union Agency for Network and Information Security.[322]

SCIENCE, COMMUNICATION AND BEHAVIOUR

Information is being collected and spread at greater volumes than ever before.[323] Inaccurate information (such as 'fake news') can spread globally via social media. Some social media sites are using human fact-checkers or developing algorithms to identify fake news. Research on how people process information can help policy-makers and organisations understand why some messages are more effective than others. For example, studies indicate that individuals respond differently to health messages when they are tailored in different ways. Biological monitoring (such as via brain scans, wearable biosensors, eye tracking or facial analysis) can also be used to study people's emotional responses to information.[324] Some consultancies are already using biological monitoring to tailor messages in political campaigns and these techniques could be used by policy-makers in the future. Public opinion on the use of these methods is unknown, although a survey of UK citizens found that they were in favour of some behavioural techniques (nudges) if they reflected the interests/values of most citizens and did not have illicit purposes.[325]

Overview of area

The rise in internet services (including online retail and social media) has allowed greater collection and dissemination of information than ever before, and the associated challenges have prompted varied responses from policy-makers worldwide. For instance, the EU has reacted to the rise of data collection on the internet by enacting legislation (GDPR) to provide consumers with greater control of the personal data that businesses and the public sector hold.[326] By contrast, the Chinese Government has responded by limiting its citizens' access to selected websites via a nationwide firewall (the 'Great Firewall of China').[327] Additional challenges have arisen from the changing ways in which individuals receive news and search for information, facilitated by the expansion of social media. This has led to a move away from sources of information that are typically viewed as better verified (such as TV, radio and newspapers). The increasing use of social media as a source of news and current affairs has led to concerns about the undue influence of 'fake news' on public opinion, and that it may counteract information from reputable agencies. For example, a recent study showed that Russian bots, trolls and 'content polluters' have been agitating debate on social media platforms about the efficacy of vaccines.[328] People can use social media to create an environment where they predominantly view content that aligns with their pre-existing opinions and interact less with those without shared ideologies.[329] These 'echo chambers' can then be used by extremist groups wishing to spread messages through a network to recruit or influence individuals.[329,330] There has been increased research into how to detect fake news in response to these challenges, along with how to ensure that accurate information is disseminated.[331,332] Some social media sites have responded to the spread of fake news by using human fact-checkers or developing algorithms to identify the hallmarks of fake news stories.[333,334]

Few campaigns admit to using neuropolitics consultants and it has been suggested that consultants can be protective of their clients' identities.

Understanding how people process information could allow greater tailoring of messages from both reputable organisations and those with ulterior motives (such as spreading fake news, promoting extremism or attempting fraud) in the future. Regardless of age, gender or social class, most individuals share information on social media without verifying if it is accurate.[335] People tend to be influenced more by their value and belief systems than the accuracy or validity of information. For example, research indicates that individuals process statements that they agree with faster than those that they disagree with, and tend to treat those that they agree with the same way as facts.[336] This may help to explain why people often remain entrenched in their convictions. Furthermore, research suggests that false news spreads more quickly through a network than accurate news.[337] Passing on news from one person to another also tends to amplify the negative content of that news. Researchers following news stories on social media found that the more people share information, the further that information gets from the truth and the more resilient it becomes to correction.[338] Studies also show that the way that information is presented can affect how people respond to it. For example, in a study of a hypothetical mass decontamination, researchers found that the most effective response came when they provided advice based on both health-focused and practical information, compared with either of these alone.[339] In a study on containing a hypothetical pandemic, researchers found that messages focusing on the possible health impact of actions were more effective than those based on information about the likelihood of passing on infections.[340] The way in which messages are formatted and presented, such as the text size and use of images, also influences how likely individuals are to pay attention to health messages, with those using large fonts and images being most effective.[341]

As well as understanding how people react to information through their behaviour, researchers have also found ways to assess how individuals respond through biological monitoring. For example, brain scanning can be used to track peoples' feelings, which could be used in the future to assess how engaging or convincing content is.[342] Furthermore, eye tracking can be used to study attention, facial analysis software can be used to gauge emotional responses, and electrical activity on the surface of the skin to assess arousal. Political parties around the world are increasingly turning to 'neuropolitics' experts to try and influence voter behaviour.[342] Consultants in this field have used monitoring techniques such as facial analysis software, eye tracking and brain scans to hone political campaign messages to maximise their impact. They may also analyse data from potential voters' social media accounts to try and personalise campaign messages to voters. Finally, some consultants analyse public reactions to electronic slogans and tailor the message accordingly in real-time.

Using personal data harvested from social media to target political messages raises complex ethical issues.

Social marketing techniques may also be used in various policy areas to allow individuals to make better-informed decisions.[343] Public opinion of how policy-makers should use research findings to shape the way they deliver information is likely to affect how widespread certain methods become. Behavioural nudges (ways of altering people's behaviour to achieve set outcomes) are already being used in various policy contexts, including health and education.[344] A survey of UK citizens indicates that the majority approve of the use of certain behavioural techniques (including nudges) if they reflect the interests/values of most citizens and do not have illicit purposes.[325] However, opinions are more divided when research is conducted into shaping attitudes in relation to military and defence.[345] Individuals may be more likely to support the use of behavioural techniques when the aims are transparent and reflect widely held views in the country, such as challenging violent extremism or other online harms.[346,347]

Implications and challenges

- Implicit in traditional ideas of democracy is the notion that voters are rational agents who make informed decisions, and that political discourse isbased on the exchange of reasoned views. Political science has previously challenged this assumption, and successful political campaigns that play on people's emotions provide evidence that runs counter to the rational model of the democratic process.

- Using personal data harvested from social media to target political messages raises complex ethical issues concerned with informed consent. For example, in the case of Cambridge Analytica, issues arise over whether people consenting to undertake a personality test also gave informed consent about having that data used in political campaigns.

- Further consideration by national governments is likely to be needed about how to regulate behavioural techniques and hold individuals or organisations accountable for the use of these techniques in marketing, influencing, campaigning and policy-making.[348] Additionally, there may be future calls for governments to equip citizens with awareness around behavioural techniques, knowledge about how they can impact decisions, and skills to deliberate in a different manner to avoid unwanted influence.[348]

- The longer-term and population-wide implications of the use of biological monitoring and interventions in decision-making environments have been identified as a key challenge to citizen autonomy, including consideration of how certain techniques could diminish opportunities for learning/self-development or could be targeted at vulnerable populations.

- Few campaigns admit to using neuropolitics consultants and it has been suggested that consultants can be protective of their clients' identities. This raises the question as to whether politicians should be compelled to reveal the methods they use during their campaigns.

- There is debate over how well the various responses measured map onto the emotions and moods attributed to them. For example, while emotions are often categorised in six basic forms (happy, surprised, sad, angry, fearful and disgusted) there is debate over how many compound emotions (like happily surprised or fearfully angry) there are, whether these can be accurately recognised by software, and whether technology can distinguish between differences in emotional responses and longer-term moods.[349]

Key unknowns

- The combination of the lack of transparency and the uncertainty about the underlying science means that there is little evidence on how effective new neuro-sensing techniques are in influencing human behaviour. It is therefore not clear if the methods could be applied to public good, such as disseminating public health messages.

- There is limited research into the extent that neuroscience monitoring data can influence voting behaviour in political campaigns, and it is not known how much influence this data has already had on political campaigns nor what the impact may be in the future.

- There is limited research on public opinion on how policy-makers should use some techniques (such as neuropolitics) in delivering information or services. There may be valid concerns from citizens about using some techniques in certain policy areas.

- It is not known whether greater prevalence of various behavioural techniques in different areas of life, and people's increased awareness of how they work, will make these techniques less effective.

ENVIRONMENTAL PRESSURES AND CLIMATE CHANGE

Sparing nature and increasing productivity Pollution old and new Climate change impact uncertainties and ecosystems

SPARING NATURE AND INCREASING PRODUCTIVITY

Threats to the integrity of ecological systems are escalating globally,[350,351] with one million plant and animal species likely to become extinct in the next couple of decades.[350] The ways in which farming and food systems are managed to meet rising demand in the next 20 years will be pivotal to the extent of these pressures, as more than one-third of the world's land surface and nearly 75% of freshwater resources are now devoted to crop or livestock production. Subsequent degradation will, in turn, affect the productivity of farming and food systems.[352] Many important external factors of farming and systems, such as biodiversity loss and pollution, are inadequately measured.[353] There is evidence that more efficient agricultural systems (with lower inputs of water, nutrients, feed, pesticides and veterinary medicines, as well as land-use per unit of production) have lower environmental impacts.[354,355,352] In many parts of the world, productivity in the food system is also below its potential for basic reasons, such as waste in the harvest and post-harvest parts of the supply chain (see Navigating the Vulnerabilities of the Food System). However, both changes in diet and reductions in food waste may be required to lower inputs sufficiently to protect biodiversity and ecological processes.[356] Changes in land use and land cover affect processes in the wider environment, including biogeochemical cycles and climate at the global scale. Analyses of 35 years of satellite data suggest 60% of land changes are associated with direct human activities and 40% with indirect drivers, such as climate change.[357] If higher food yields of greater nutritional value can be obtained from land already being farmed (usually referred to as sustainable intensification), other land can be taken out of production and restored as natural habitats for wildlife, and carbon or floodwater storage, particularly in countries that still have areas containing highly valued biodiversity.[358]

Overview of area

Producing more food from less land will require both large-scale changes and incremental improvements implemented as part of a systems-based approach that considers both the environment and agriculture.[359] An example of such a large-scale change required is reducing the amount of land use and greenhouse gas (GHG) emissions for the production of livestock feed by moving to novel sources, with options such as industrially-produced microbial protein,[360] or insect protein (POSTnote 499). An example of incremental technological change includes the gene editing of crops, using techniques such as CRISPR, to introduce traits more quickly and precisely that increase yields or improve nutritional profiles. For example, in China a gene-edited variety of rice has recently been field-tested and demonstrates higher production of grain per plant (25%–31%).[361] In the laboratory, varieties of rice have been gene-edited to increase iron and zinc levels, and potato varieties edited to enhance levels of vitamin B6 and increase resistance to physical stressors such as salinity.[362,363] Increased availability of information about the genomes of major crops will allow breeders to develop crops with multiple traits that enhance productivity and nutrition.[364] Novel food crops could also be developed from wild species related to existing crops.[365]

Novel approaches may also be needed to address the environmental sustainability of agricultural inputs, such as fertilisers and pesticides. For example, engineering nitrogen fixation activity in crop plants has proved to be a complex problem, but an alternative approach to engineer nitrogen fixation in plant cell organelles using bacterial genes may be easier to achieve.[366] Increasing understanding of plant microbiomes may also facilitate their manipulation to combat plant diseases and reduce the need for fertilisers.[367] Disease, pest and invasive species pose a growing threat to crops and the ecology of the farmed environment. Humans introduce such non-native species repeatedly in large quantities, in ways that can help free them from their usual predators and competitors. Research suggests this can disrupt species co-existence, leading to eventual extinctions, especially when combined with other forms of environmental change.[368,369] The ecological impacts of many introductions are unknown, such as the global introduction of hammerhead flatworms that are predators of soil animals, including earthworms, and a possible threat to soil ecology.[370] Emerging strategies for crop protection involve the external treatment of plants with double-stranded (ds)RNA to trigger RNA interference in crop plants to defend against plant viruses and other disease-causing organisms (similar to a vaccination).[371] Bioprospecting in extreme environments may also provide novel antimicrobials to address resistant pests, such as from marine Antarctic fungi,[372] and increased understanding of the life-cycle and genetics of pests may highlight emerging problems.[373] Technology will also contribute towards increasing productivity, by increasing yields while reducing inputs;[374] for instance, using lightweight, high-resolution imaging sensors on unmanned aerial vehicles to measure the presence and state of vegetation to quantify crop health, moisture and nutrient content. In the longer term, technologies such as aeroponics (the process of growing plants in an air or mist environment) vertical farms or 'cellular agriculture' technologies, such as meat and fish cells grown in the fermentation vats and milk produced by biosynthetic yeast cells, may reduce inputs to a minimum; although regulatory, energy use and technical challenges remain to be addressed.[375,376, 377,378,379,380,381]

6 million square kilometres, or 32.8% of the Earth, are under intense human pressure.

Implications and challenges

- Protected areas are the primary defence against biodiversity loss and degradation of ecosystems. Although the percentage of land included in the global protected area network has increased from 9% to 15%, extensive human activity within the boundaries of this protected land, such as mining, logging and the building of roads and powerlines, suggests that 6 million square kilometres (32.8%) is under intense human pressure.[382] Earth observation studies have shown that protected areas in Europe, and the species they shelter, are subject to a range of pressures, including increased use of land for agriculture and encroachment by invasive species.[383]

- Ensuring global food security is the second of 17 Sustainable Development Goals adopted by the United Nations as part of its 2030 Agenda for Sustainable Development but achieving this while reducing negative environmental impacts is one of the greatest challenges facing humanity.[384,385] Water availability is already a major constraint where agriculture is dependent on irrigation, which will have an increasing impact on productivity with climate change.[386]

- Complex biodiversity change may also be affecting the integrity of ecosystems before the implications of these changes are understood.[387,388,389] For example, 'keystone' species that play important ecological roles; such as predators, pollinators and recycling nutrients; on which other species and the resilience of ecosystems depend are sensitive to human-driven pressures,[390,391,392,393,394,395] including habitat loss, climate change, invasive species, pesticides and nutrient pollution, which may have implications for food security.

- Creating an environmentally sustainable food system that meets increasing global demand will require more than improved agriculture productivity.[352] This includes reducing food waste from 'farm to fork', as according to the Food and Agriculture Organization, roughly one-third of the food produced in the world was wasted in 2011;[396] addressing this could also increase food security.[397] It will also require changing food behaviours of consumers, including dietary choices, such as reducing the animal source foods with the highest environmental impacts.[398] Strategies are needed for managing land use and food systems together (see Navigating the vulnerabilities of the food system), which consider links between agriculture, water, pollution, biodiversity, diets and GHG emissions.[399]

- Regulatory frameworks may help or hinder technological changes. For example, in March 2018 the US Department of Agriculture stated that it had no plans to regulate gene editing of plants that otherwise could be developed via traditional breeding techniques,[400] whereas in July 2018 the European Court of Justice judgement set out that gene-edited crops should be subject to the same stringent regulations as conventional genetically modified organisms.[401]

Key unknowns

- How agricultural intensification affects both ecosystem services and human well-being in low- and middle-income countries is not well understood, and the available evidence suggests that they rarely lead to increases in both ecosystem service provision and human well-being.[402] Social ecology, the study of interdependent relationships between people, institutions and the environment, may be one option for informing integrated approaches to sustaining the multiple functions of landscapes.

- Developing systems for optimal land sparing (for biodiversity) will require approaches for incentivising or regulating uses of land at both the national and international level, as well as the relevant evidence base to inform land sparing strategies.

- Restoring or creating habitats on spared land may involve challenging timeframes, and the evidence base is limited to a few types such as grasslands. A review of eco-engineering approaches for coastal urban infrastructure showed increased abundance or number of species for all but one intervention,[403] suggesting that more can be done to mitigate or compensate biodiversity impacts. Technological advances may also make it possible to 'resurrect' extinct species, but the ecological implications of this are unknown. For example, a near-complete genome of the little bush moa, which became extinct in the 13th century, has been recreated.[404] Such novel approaches may be controversial, but a 'cooling-off effect' can lead to increased public acceptance of new environmental technologies over time.[405]

- Creating effective agricultural innovation systems; the UK has an agricultural research and development base of institutes and universities as well as four agri-tech centres and a funding initiative under the Industrial Strategy. However, overall public investment in agricultural investment has been declining, such as the decline in Defra's research budget; and there are issues around the coordination of funding streams, improving translation of longer-term research, an onus on competition as opposed collaboration and a lack of incentive systems to encourage innovation.[406]

- Which innovations are likely to be publicly acceptable within the food system, such as using insects or microbes as novel sources of animal feed, will relate to factors such as how risks are perceived, values and trust. Moving to systems such as lab-grown meat would also have implications for livelihoods across the food system.

POLLUTION OLD AND NEW

Environmental policies guided by science have managed to control and reduce emissions of many toxic substances over the past few decades, leading to measurable reductions in exposure and effects, such as the removal of lead from petrol. At the same time, there have been increases in other polluting substances dispersed into the environment by a range of uses and activities, many of which have been associated with environmental and human health effects, especially in relation to chronic exposures despite their lower acute toxicity. An understanding of the effects of these pollutants continues to emerge, such as air pollutants from transport. There are significant knowledge gaps for substances that have become of concern more recently, such as the impacts of widespread contamination of microplastics on the oceans and potentially the food chain. Contaminants of emerging concern (CECs) are pollutants that are currently not regulated (not submitted to a routine monitoring and/or emission control regime) but may be under scrutiny for future regulation. Most CECs are substances that have been entering the environment for years, even decades, such as pharmaceuticals and personal care products, although their presence has only recently begun to be investigated. However, the list of compounds is also constantly growing, with new industrial materials and formulations being added.[407]

Overview of area

Extensive regulation has sought to address the burden placed on human health and the environment by pollutants since the mid-20th century, with some success. In the case of air pollution, clean air Acts passed in 1956 and 1968 in the UK, along with subsequent legislation, led to considerable improvements in air quality and a reduction in the acidity of precipitation and surface waters. Similarly, since the Clean Air and Clean Water Acts enacted in the 1970s in the US, long-term monitoring sites have recorded declining concentrations of airborne pollutants such as sulphur, nitrogen, mercury and lead, with subsequent measurable decreases in human body burdens and morbidity. Visibility-limiting haze and concentrations of ground-level ozone have also decreased.[408] The release of pollutants to air has been limited in the EU through regulatory frameworks, such as the Air Quality Directives, the Industrial Emissions Directive and the Regulations setting emission limits from vehicles. However, air pollutants still occur at levels that well exceed the World Health Organization guideline values in the UK, such as nitrogen dioxide and particulate matter (PM).[409] New understanding of these well-known air pollutants is still emerging; for instance, environmentally persistent free radicals (EPFRs) are contaminants contained in $PM_{2.5}$ (particulate matter less than 2.5 micrometres in size). The ultrafine particulate matter components (under 100 nanometres) of $PM_{2.5}$ contain EPFRs,[410] by-products emitted from organic materials that react with and form on the surface of particles of transition metal oxides, such as copper or iron oxide. Studies have suggested these substances may be responsible for some of the human health effects more broadly attached to particulate matter.[411] Non-exhaust particles from road traffic now exceed emissions of exhaust particles, particularly coarse particulate matter (PM_{10}), with particles from brake, engine and tyre wear including elements such as copper and iron.[412,413] Tyre wear and road surface wear currently constitute 60% and 73% (by mass), respectively, of primary $PM_{2.5}$ and PM_{10} emissions from road transport, and will become more dominant in the future.[414] New data are also being gathered on the sources of transport pollutants; for example, a data register study of chemicals in products related to motorised transport in Norway identified a diverse range of substances that were classified as hazardous to either human or environmental health.[415] Volatile organic compounds are air pollutants involved in the formation of ozone pollution (POSTnote 458). Studies suggest solvents and compounds used in personal care products have now replaced road transport as the largest source of urban emissions.[416]

New understanding of the health and environmental impacts of well-known pollution problems continues to emerge.

Microplastics, tiny particles under 5mm in length, are now present across air, soil and sediment, freshwaters, seas and oceans, plants and animals, and in several components of the human diet, but remain one of the least studied groups of contaminants (POSTnote 528). The best available evidence suggests they do not pose a widespread risk to humans or the environment, but this evidence is limited, and the situation could change if pollution continues at the current rate.[417] These particles come from a variety of sources, including plastic products, textiles, fisheries, agriculture, industry and general waste. Research on the sources of microplastics in rivers suggested that wastewater treatment plants led to increased levels, but other important sources of microplastics in the rivers studied may include atmospheric deposition, agricultural land to which sewage sludge has been applied, and diffuse release of secondary microplastics following the breakdown of larger plastic items.[418] A study of patterns of microplastic contamination in northwest England, classified by type, size and density, in channel bed sediments at 40 sites across urban, suburban and rural river catchments showed that floods "flushed out" approximately 70% of the microplastics stored in river beds, equivalent to almost a tonne of plastic, or nearly 50 billion particles.[419]

A meta-analysis of over 143,000 publications has suggested about 14 years go by from identifying a contaminant of emerging concern to the first peak of public concern, with another 15 years of scientific research activity before concern levels off at a new baseline, with peak publication activity for microplastics estimated to be in 2022.[420] Other emerging contaminants of concern include natural or manufactured chemicals from common household and personal care products, pharmaceuticals and plant protection products, which are frequently detectable in environmental samples including wastewaters and in human and wildlife tissues. They have uncertain health and environmental consequences, such as increased antibiotic resistance or endocrine disruption (adverse effects on the functions of organisms' hormonal systems).[421,422] One example is gadolinium complexes (used in magnetic resonance imaging) that have been found in aquatic environments in low levels. Emissions of these are expected to increase and there is a lack of detailed studies on degradation, metabolism and bioaccumulation of these substances.[423]

Implications and challenges

- Despite the widespread adoption of principles, such as the polluter pays and rectification at source, regulation of diffuse pollution sources, such as diesel vehicles, has not been effective compared to regulation of point source pollution. Some pollution sources could be described as re-emerging, such as wood smoke. Despite falling to very low levels a couple of decades ago, the increased popularity of open fires and particularly wood burning stoves is leading to a significant contribution of wood smoke to $PM_{2.5}$ in the UK atmosphere.

- New understanding of the health and environmental impacts of well-known pollution problems continue to emerge, such as air pollutants from transport, heating and agricultural sources, but a systems-based approach to reducing their emission remains challenging to implement.

- Some pollutants, such as microplastics, that are transported globally will need to be addressed at the international level. Reducing levels of persistent substances that are widespread in the environment, such as mercury or persistent organic pollutants (POPs), can take decades or centuries (POSTnote 579).

- Existing testing regimes for chemicals may be insufficient for screening novel substances, such as nanomaterials (substances measuring approximately 1–100 nm in length that have size-dependent unique properties, POSTnote 562), and there is a lack of studies on their fate, behaviour and effects of some novel pollutants in the environment.

- Eurostat has developed a set of indicators to monitor progress towards two major goals of the Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH): to improve the quality of data for chemical risk assessment, and to reduce the risks posed by chemicals to humans and the environment.[424] The consumption volumes of industrial chemicals (i.e. the amount manufactured) hazardous to health and the environment is used as a rough proxy for exposure. From 2004 to 2016, consumption decreased by 11% in the EU, but the European Environment Agency suggests that estimating chemical risk is difficult because there is incomplete information on the hazards of chemicals and exposure from other sources, such as the legacy of persistent chemicals in the environment and recycled products.[425]

- If Defra's stated objective in the 25 Year Environment Plan of managing exposure to chemicals is to be realised, many challenges will need to be addressed, including improving monitoring programmes and implementing remediation strategies as implementing regulatory actions, as well as considering the effects of complex mixtures of chemicals and the effects of changing climactic conditions on chemicals in the environment, which can interact.

Key unknowns

Although ubiquitous in the environment, the fate and effects of microplastics are still poorly understood. Despite some laboratory studies suggesting possible effects on marine food chains,[426,427] a recent review of the available evidence suggests they do not pose environmental or health risks, although it also highlights the limitations of the evidence.[417]

Nanomaterials may be an example of how the introduction of new materials can drive public concern and boost in research activity, leading to the development of new regulations,[420] but the wide range of forms and uses of nanomaterials present many regulatory challenges for assessing the risks they pose (POSTnote 562).

It is unclear which environmental contaminants are likely to be propelled to the forefront of public concerns by the development of novel detection techniques or new scientific understanding.

CLIMATE CHANGE IMPACT UNCERTAINTIES AND ECOSYSTEMS

The ongoing emission of greenhouse gases (GHGs) are triggering changes in many climate hazards that can impact ecosystems and human well-being. The recent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) global assessment report highlighted that climate change is already having an impact on nature, from genes to ecosystems.[350] The IPCC will publish two special reports later this year, one on climate change and land (desertification, land degradation, sustainable land management, food security, and GHG fluxes in terrestrial ecosystems), and one on climate change, oceans and the cryosphere. The IPCC Special Report on Global Warming of 1.5°C presented several possible pathways to zero global carbon emissions by 2050, and achieving all of these relies upon removing the carbon dioxide (CO_2) from the atmosphere with Greenhouse Gas Removal (GGR) techniques (POSTnote 549).[428] Some rely upon 'overshooting' emissions reductions and subsequently needing greater removals. In such a scenario, risks from climate hazards may be realised before levels of GHGs can be reduced. However, some climate hazards remain poorly understood, such as feedbacks, rapid changes, and tipping points in the climate system. For instance, methane may be released from melting Arctic permafrost making warming worse; or from methane hydrates under the sea, or carbon from forest degradation and fires.[429,430] The recently proposed amendment to the Climate Change Act 2008 to be carbon neutral by 2050 will require more rapid climate action, requiring better understanding of human systems and just transitions.[431]

Overview of area

Despite widespread agreement on the direction and magnitude of warming, there are a range of uncertainties in how region-specific earth system properties and processes will respond to changes in climate, and how accurately they are represented in models. Research has suggested that some regions of the world, such as the Arctic and Southeast Asian monsoon region, could be more sensitive to changes to global temperatures than previously assumed, and could lead to rapid losses of greenhouse gasses as part of climate-carbon-cycle feedbacks.[432,433] In the case of the Arctic, for a large fraction of the ice-free land area including the Canadian high-Arctic archipelago and the Arctic coastline of Russia, there is a lack of observations and research, despite being one of the most rapidly warming regions. Arctic research tends to be biased in favour of sites that are well-connected and well-resourced.[434] Significant uncertainties remain about positive climate feedbacks of methane release from natural systems, such as the physical and microbiological processes involved in permafrost melting in the Arctic,[435] as well as changes in the decomposition of sediments in freshwater lakes in the northern hemisphere.[436] Many additional studies suggest some of the risks posed by climate change impacts are not yet fully understood.[437,438,439,440,441] For instance, permafrost in the northern hemisphere stores globally significant amounts of mercury (793 gigagrams ten-fold greater than the level of emissions from all human activities for the past 30 years), which may be released as it thaws affecting ecosystems and human health.[442] There is also ongoing discourse about the influence of Arctic changes on weather patterns, such as whether reduced temperature differences between the North Pole and equator slows down the movement of weather systems causing them to become more persistent.[443,444]

There has been 1°C of warming to date, and current international pledges could result in 3.2°C by 2100.

Human interactions with terrestrial ecosystems can increase climate risks. Many land areas are currently important sinks for carbon due to the CO_2 fertilisation effect and longer growing seasons in northerly areas. However, changes in land use and climate change in some regions will have a significant impact on future CO_2 absorption from the atmosphere, even causing some regional reversals of carbon sinks and greening, particularly at the edges of the Amazon and African rainforests, such that these areas become carbon sources.[445] Tree mortality rates also appear to be increasing in moist tropical forests, because of factors including rising temperatures, drought, fires, more potent storms, and insect infestation. However, "hydraulic failure" from a lack of water combined with "carbon starvation" due to closed stomata (tiny pores in plant tissues that allow for gas exchange) are likely to be the main causes.[446] When more CO_2 is present, stomata do not open as widely, which reduces the amount of water evaporated into the atmosphere via transpiration, this is a small process at the plant level but when multiplied across the rainforest, may cause changes in the atmosphere that affect the way winds blow and the flow of moisture coming from the ocean, with modelling suggesting that this may dry out the Amazon rainforest in the future.[447]

Current emission pledges under the Paris agreement would lead to 3.2°C of warming (compared to pre-industrial temperatures) by the year 2100, under which 49% of insects, 44% of plants, and 26% of vertebrate species would lose half their geographic range with significant effects on terrestrial ecosystems.[448] The rise in CO_2 levels and subsequent increasing acidity of seawater could also affect the organisms involved in carbon cycling by the oceans and marine ecosystems,[449] with marine organisms also affected by projected changes in sea temperature, the stratification of sea water and oxygen content, as well as storm conditions and sea levels resulting from climate change (POSTnote 604).

Implications and challenges

- Annual human-induced CO_2 emissions are increasing; in 2018 global emissions were estimated to be 2.7% higher than in 2017.[450] If the Paris Agreement targets are to be met, emissions will have to decrease. There has been 1°C of warming to date, and current international pledges could result in 3.2°C by 2100. To achieve the 1.5°C target, modelling suggests that global CO_2 emissions would need to peak in the next few years and be in decline by 2030, reaching net zero around 2050.[451]

- If instead an approach of overshooting emission targets and then removing CO_2 from the atmosphere was adopted, ecosystems will be affected by the temporary rise in temperature and these effects may be irreversible, such as the extinction of species that experience a reduction in their geographic range.[452]

- Some novel approaches to modelling effects on ecosystems are being developed.[453,454,455] This includes linking mathematical or statistical models of disease transmission to scenarios of projected climate change,[456] to understand changes in human health risks from vector borne diseases as insect vectors move into new areas and disease dynamics change (POSTnote 597).[457]

- Marine biodiversity is affected by multiple physical and chemical drivers (leading to ocean warming and ocean acidification) and by diverse ecological processes that are also being altered by climate change and other human drivers of environmental change. However, research to reduce uncertainties is needed to predict the responses of marine organisms and ecosystems to global ocean change.[458] Business-as-usual emissions will likely disrupt many marine ecosystems, reducing the benefits of Marine Protected Areas that have been suggested as a means of adaptation for marine biodiversity.[459]

- Arctic ecosystems may be greatly changed as sea-ice melts, especially if this opens up new shipping routes or opportunities for resource exploitation (there are significant oil, gas and mineral reserves in the high latitudes).[460]

- Some poorly characterised climate hazards such as the influence of Arctic changes on weather patterns could have significant impacts on human well-being in various parts of the world.

- Coastal ecosystems are amongst the world's most valuable,[461] but the increase in sea-levels present threats to these systems if rates of rise outpace the ability of coastal systems (human and biological) to adapt, with no coastal nation being unaffected.[464]

Key unknowns

- Interactions between climate change and land use change may lead to losses of biodiversity, and poor species health, leading to negative consequences for the functioning of ecosystems and consequences for human well-being.[462]

- The range of some insects that are critical for ecosystem functioning (e.g. pollinators) have already changed with current levels of warming,[463] and insect species may continue to decline rapidly in response to climate change

- There could be expansion in the range of disease vectors,[464] such as insect vectors involved in the transmission of bluetongue virus,[465] as well as in incidence of disease.

- Marine zooplankton are in high abundance in climatically-important regions of the ocean, and their loss may considerably alter the physical and biogeochemical structure of the water column, with potentially widespread effects on fish stocks and ocean carbon uptake, but these effects are not yet well-characterised.[466]

- Global warming is the main cause of marine oxygen loss. It affects the ocean in several ways including lowering the solubility of oxygen in the water and changing patterns of global ocean circulation, reducing supplies of oxygen throughout the ocean, including in the deep ocean. The extremely complicated interactions between biological, chemical and physical processes in the ocean are difficult to represent in current models.[467]

- All the pathways for limiting climate change to 1.5°C include the use of GGR technologies, such as afforestation and bioenergy with carbon capture and storage (BECCS). Depending on the amount of GGR required, this could involve growing trees or biofuel crops on a large scale (hundreds of millions of hectares), which could cause biodiversity declines. Doubts have been raised as to the feasibility of this and the trade-offs between BECCS and other land uses.[468] The speed at which carbon capture and storage can be developed and deployed is also a major remaining uncertainty; operational plants are still only at pilot stages.[469] Therefore, synergies, constraints and trade-offs in the potential of GGR technologies need further attention.[470,471]

- Atmospheric methane has grown very rapidly since 2014 at rates not observed since the 1980s, but it is not clear whether this is a result of growing emissions of methane, from wetlands, agriculture and the natural gas industry, or a slowing of the sinks for methane, including destruction by atmospheric chemistry and the soil bacteria that consume methane.[472] Researchers have also suggested that the possible GGR approaches for removing methane from the atmosphere should be evaluated for their capability for pre-industrial level reductions.[473]

- While carbon emissions from energy use are fairly well quantified, there are larger uncertainties regarding anthropogenic greenhouse gas emissions from land use, wastes, fertiliser production, and use of certain chemicals.[474,475,476] Improvements in data (including the use of satellite observations) and methods can ensure transparency and credibility of monitoring reporting and verification of greenhouse gas emissions and removals, as well as country actions under the Paris Agreement, UK actions under the Climate Change Act 2008, and the actions of cities and businesses.[477,478]

RESOURCE SECURITY AND SUSTAINABILITY

Energy and resource security challenges Navigating the vulnerabilities of the food system New low carbon energy systems

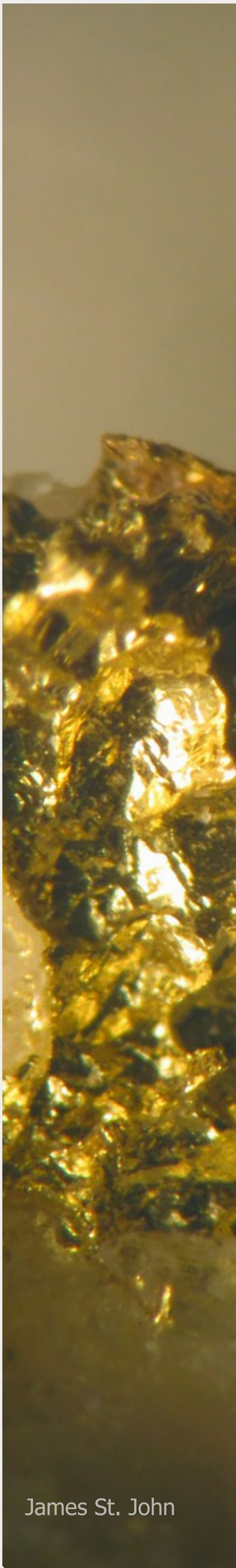
ENERGY AND RESOURCE SECURITY CHALLENGES

Resource security – defined as the ability of a state to ensure sufficient provision of resources (such as energy, minerals, water and food) to meet the needs of its population and the economic processes within it – is a key policy aim of national governments. The dual aims of decarbonising economies quickly enough to avoid the worst effects of global climate change while maintaining resource security is likely to be a defining challenge of the 21st century. There may be challenges to UK energy security (such as from geopolitical dynamics or changing electricity generation technologies), food security (from climate and demographic change, or increasing amounts of land and water used to grow crops for bioenergy) and security from the geographic concentrations of rare earth elements. However, some areas of technological change may open new avenues for ensuring resource security, offsetting some of these challenges.

Overview of area

Energy security is defined by the International Energy Agency as the uninterrupted availability of energy sources at an affordable price.[479] It can be measured in a number of ways, including sovereignty measures around import dependence and the amount of resource sourced domestically, economic measures of the extent to which national consumers are shielded from rapid changes in resource prices (volatility), or technical measures of the reliability of a network (e.g. electricity grids) to be able to supply enough energy to meet demand at any time.[480,481] Security may also be raised around broader resources, such as certain metals required for advanced manufacturing.[482] A number of geopolitical and technological factors may lead to growing challenges to energy and resource security, across all of these definitions, over the coming decades.[483]

The production and trade of fossil fuel resources is often used as a geopolitical tool for enhancing economic and security power. There are concerns that risks to European energy security may arise as a result of dependence on Russian natural gas; many EU states import natural gas from Russia, either via one of several pipelines or, to a lesser extent, via 'liquefied natural gas' (LNG) transported by ship. Tensions surrounding this trade route have escalated since 2014, when Russia prevented gas flowing through Ukraine into Europe, and later when Germany confirmed it would develop a second 'Nord Stream' pipeline bilaterally with Russia.[484,485] Concurrently, in recent decades, the US has substantially increased shale gas production and its LNG export, and a greater proportion of US LNG could begin to be redirected to Europe.[486,487] These factors in combination have led to commentary over the future supply of the European gas market.[488] In the UK, a perceived lack of gas storage (following the closure


James St. John

of the UK's main storage facility) and declining domestic production have led to concerns from some commentators over energy security.[489] Academics and industry experts also highlight challenges presented by the ageing condition of certain 'midstream' infrastructures (such as pipelines and storage facilities); unfavourable gas market dynamics, including the closure of the Groningen gas field in the Netherlands; and uncertainties around future energy governance, for example those presented by Brexit.[490,491]

Cobalt is a necessary material for battery technologies, but the majority of the world's reserves are mined in the Democratic Republic of Congo

Technological change, driven by climate change and emissions objectives, is facilitating an unprecedented change in the energy system, which has the potential to make meeting the day-to-day energy demands from consumers more difficult. Many commentators have raised concerns that a more 'flexible' electricity system (characterised by more variable energy supply and greater management of demand) could face challenges in meeting peak demand without back up from conventional generation.[492,493] Projections of future UK energy scenarios vary,[479,494] but there is general agreement that successfully meeting both energy security and decarbonisation objectives requires focusing on maintaining energy system resilience (technologies that can help alter supply or demand, interconnection with overseas markets, and market designs that can unlock flexibility on the demand side). However, new technologies and processes may help to offset some of the challenges of meeting energy and resource objectives sustainably. Overall electricity demand has been in decline for more than a decade, as more efficient technologies, homes and products proliferate. This trend may continue if policy or market conditions continue to drive more efficient processes, circular design product principles and consumer choices around 'green products'. For example, new or more efficient recycling can reduce resource use, enhancing security.[495,496,497,498] Other more radical innovations – such as blockchain or machine learning – may lead to new approaches altogether.[499,500] Energy and resources could even be found in new places entirely, such as in the deep seas or outer space.[501,502]

Implications and challenges

- If UK natural gas storage levels are low, imports remain high and current infrastructure risks persist (such as the age of some North Sea pipelines and a lack of storage); residential or industrial consumers could face price volatility risks. This is particularly the case if extended periods of cold weather reduce supply margins. In some more high-risk cases, supply could be interrupted altogether.

- Technological and regulatory challenges can arise from operating an increasingly complex power system, which will likely require new approaches to network management. There are specific difficulties associated with operating the power network, including the provision of certain services such as black start, frequency response and inertia; historically provided by large fossil fuel stations. New approaches to managing these are being developed and will increasingly be relied upon.

- Political tensions or instability may cause disruptions to material or energy flows into the UK. For example, cobalt is a necessary material for battery technologies, but the majority of the world's reserves are mined in the Democratic Republic of Congo.[503,504] Many rare-earth metals are mined predominantly in states such as China.[482] Such high concentration of production can leave supply vulnerable to political or economic disruption.[505,506,507]

Key unknowns

- Despite UK ambitions on climate change mitigation, there is a political risk that emissions reduction may be de-prioritised in the case of unforeseen economic challenges, for example, following an economically unfavourable withdrawal from the European Union. In addition, the UK's future relationship with the EU may affect the efficiency of trade across electricity and gas interconnectors.[508,509]

- There are unknowns around the future development of critical materials markets. Without innovations in many technologies that use such materials, demand could increase substantially. In combination with potential supply-side concerns, such as political instability, this could lead to price volatility and resulting challenges in some energy technology markets.

NAVIGATING THE VULNERABILITIES OF THE FOOD SYSTEM

Food production and consumption drives environmental change, such as climate change that in turn may affect food production systems, though these effects are often poorly understood. Food is part of wider, more complex system than merely a chain from production to consumption and disposal; there are interactions with the environment, health and society at the systems level. This means that the social and economic vulnerabilities created by having a globalised food system, that interacts with water, energy, waste and transport, are difficult to mitigate. Taking a 'systems approach' means looking at connections between the different parts of a system, understanding where activities in one part of the system impact on another – intentionally or unintentionally – and where there is feedback, or broken feedback, between parts of that system. Without a better understanding of the natural systems supporting food production, the social and economic costs of the trade-offs being made for long-term outcomes may not be fully understood until the risks of such decision-making are realised. A wide range of factors can influence food supply, from natural disasters (flooding), infectious diseases (foot and mouth disease) to technological accidents (the Chernobyl nuclear accident). Maintaining a fully functioning food system that has the capacity to absorb environmental shocks (POSTnote 543) as well as being flexible and adaptable to other changes, such as the values and ethics of consumers, requires sufficient regard for risks that can arise from combinations of factors such as low financial margins and profitability, loss of consumer trust and weather events affecting crop yields and price volatility.[510,511,512]

Overview of area

The ecological effects of environmental change driven by human activities are not fully understood and may be affecting food production systems. Fish is the most consumed protein by humans on the planet and underpins the livelihoods of many fragile communities, especially in Africa and Asia. Top predators in several aquatic food webs, including fished species, regularly display elevated reproductive failure, caused by thiamine (vitamin B1) deficiency. The reasons for these low thiamine levels are not understood and data on the transfer of thiamine from producers (bacteria and phytoplankton) to higher trophic levels are limited. However, lab-based experiments have suggested that blooms of cyanobacteria—toxic blue-green algae – caused by an excess of nutrients from agriculture can starve zooplankton of thiamine, which may affect species higher up the food web.[513] Eutrophication, in part caused by excess phosphorous in the water systems, is partly responsible for this. Fishing is one of the most widespread activities by which humans harvest natural resources. Industrial fishing occurs in more than 55% of ocean area, has a spatial extent more than four times that of agriculture,[514] and is affected by a range of environmental changes driven by human activities. For example, 72 known species of seagrass carpet coastlines across the planet, providing a safe nursery habitat and a source of food for 21.5% of the world's largest 25 fisheries, including the most landed commercial fish globally, walleye pollock. Coastal development, excess nutrients from agriculture, and damage by recreational boats and fishing trawlers have already destroyed 7% of global seagrass habitat, and warming coastal waters caused by climate change will reduce seagrass growth rates further.[515] Climate change will have a range of effects on fisheries (POSTnote 604); for instance, the proportion of large fish in the North Sea may decrease as climate change unfolds, by as much as 60% in some areas.[516] This is due to the effects of sea surface warming on primary productivity at the base of the marine food web (marine algae called phytoplankton), which has declined in the North Sea over the last 25 years affecting the marine food webs that seven commercially important fish stocks are part of.[517] Fish stock deficits provide a motivation for fraudulent activities to occur in food supply chains, such as fish species substitution; already a widespread global problem.[518]

Climate change may also affect the nutritional value of crops and vegetables,[519,520] and heat stress could change cow's milk production in southern England, suggesting effects on the quality and quantity of agricultural production.[521] Although the links between antibiotic use in agriculture and antibiotic resistance in human pathogens are starting to be understood (POSTnote 595), the recent rate of emergence of pathogenic fungi that are resistant to the limited number of commonly used antifungal agents, including for crops, is also rising. To avoid critical failures in medicine and food security, better stewardship of extant chemicals, such as azoles, is needed, along with promoting new antifungal discovery, and leveraging emerging technologies for alternative solutions.[522] It has also been suggested that global shipping of feed could result in viral pathogens being transmitted worldwide to livestock and wildlife, such as African swine fever virus.[523] Increasing demand for fats and oils, such as palm oil in food and animal feed, could lead to significant biodiversity loss.[524] However, adopting novel production approaches to reduce impacts on biodiversity could have unforeseen effects. For example, as an alternative to using oil from wild-caught fish in aquaculture feed, oilseed rape has been genetically engineered to produce the relevant omega 3 fatty acids. These fatty acids are not found in terrestrial ecosystems and caused butterfly larvae feeding on the crop to develop deformed wings and to be heavier adults, suggesting the spread of these edited genes to wild relative species could result in unintended ecological and evolutionary effects.[525] New understanding is also emerging of known critical interactions such as water systems; satellite tracking of global trends in freshwater from 2002 to 2016 has revealed new hotspots of overuse of water resources.[386] However, what works in local contexts to reduce water use, such as effective water conservation measures in different cities,[526] and the extent to which these can be delivered over relevant time frames (such as a significant reduction in household water consumption by 2065)[527] is less well-characterised.

The risks posed to global food production systems by environmental change driven by human activity are only just beginning to be understood.

Implications and challenges

- The risks posed to global food production systems by environmental change driven by human activity are only just beginning to be understood, and there may be limited time to identify and implement measures to increase resilience, characterise potential shocks and triggers, and/or reduce social and economic pressures. Increasing global food production, while continuing to degrade resources such as soil, water and climate, will exacerbate the risks to the food system.[511]

- There is an increasing focus on 'good governance' – making food policy more transparent and integrated across policy areas, and participatory. However, to achieve this will require a better analysis of connections between policies addressing food systems on an interdisciplinary basis and building understanding and capacity within government on the connected nature of food systems.[528]

- Novel approaches to addressing the ecological effects of environmental change will need audited field-scale assessments of the benefits and cost effectiveness, along with environmental monitoring for possible unintended consequences.

- Agricultural production is affected by interactions with insects, which are also being affected by environmental change. For example, climate change is likely to increase crop losses to insect pests, particularly in temperate areas.[529] Current agricultural practices have led to declines in pollinators, such that there is lower bumblebee colony success in agricultural compared with urban environments.[530]

- Current diets and production practices are degrading terrestrial and aquatic ecosystems, depleting water resources, and increasing greenhouse gas emissions, which in turn affects agricultural production (POSTnote 589 and POSTnote 600).[531] Technological innovation, reducing food waste, and dietary changes to a more plant-based diet will all be needed to transform the food system.[532]

- Agricultural, horticultural and aquacultural enterprises are having to achieve productivity gains of between 1%–2% per annum to 'standstill' economically, limiting their ability to afford unexpected costs.[511,533]

- Climate change is adding to the already considerable complexities and uncertainties inherent in fisheries science and management and promises to change the productivity of many fish stocks. Ecosystem-based management approaches that attend to habitat, species interactions, and other ecosystem components and processes has the potential to increase fisheries' productivity and resilience, even as climate changes causes many adverse effects, but will take time to develop (POSTnote 604).[534]

Key unknowns

- Whether technological approaches, such as cellular agricultural systems, will reduce vulnerabilities within the relevant time frames for the developing risks to be mitigated.

- The extent to which novel agricultural production approaches could mitigate some environmental changes cost neffectively, such as biogeochemical improvement of cropland soils with crushed silicate rocks to enhance carbon absorption while restoring soil fertility and structure.[535]

- Interactions between the water-energy-food production systems (the WEF nexus) are a key source of vulnerabilities and risks (POSTnote 543), but complex ideas of policy integration across sectors have often failed and may not protect the most economically and socially vulnerable.[536] Approaches such as agent-based modelling and fuzzy cognitive mapping can be used to understand the implications and challenges of achieving transformational change at different scales of the WEF nexus and engage stakeholders, but this is an area of emerging research.[537,538,539]

NEW LOW CARBON ENERGY SYSTEMS

The energy that underpins individual and economic activity – electricity, heating and transport – is provided via a complex system of networks, markets, regulations and other processes. Currently, these systems are a cause of substantial greenhouse gas emissions. To meet long-term climate change mitigation targets and other sustainability goals, energy systems domestically and internationally are changing. Electricity – a multi-purpose energy vector that can be used in a wide range of applications – is increasingly being supplied by weather-dependent renewables rather than fossil fuels. New approaches are also required to supply heating and transport. These may increase demand for power or use alternative energy vectors such as hydrogen gas. In any case, these changes will likely be far-reaching and unprecedented, with implications for economic, environmental and social systems.

Overview of area

Electricity and heating systems account for roughly a quarter of global greenhouse gas emissions, and transport systems roughly 15%.[540] In 2018 in the UK, transport accounted for 33% of carbon dioxide emissions, while energy supply (including power generation) contributed 27%.[541] New and emerging technologies in these areas,[542] as well as international ambitions to mitigate climate change, are leading to substantial changes in the forms of energy used to provide power, heat and transport, along with the systems underpinning them. Increasingly, these are being considered using a 'multi-vector' approach,[543,544] in which new energy carriers, such as hydrogen gas, are used across end-uses and sectors. Hydrogen can be used for heating, transport and power, and researchers and other experts are considering its potential economic, social and environmental impacts.[545,546] Electricity is a more established energy vector, though power systems in the UK are evolving due to long-term trends in:[542,547]

Industry is a particularly challenging sector to decarbonise because of its demand for high-temperature heat, among other factors.

- Decentralisation. Small-scale power generation, such as solar or wind power, situated close to consumers is likely to provide an increasing proportion of power supply.[548,549,550]
- Decarbonisation. To reduce greenhouse gases from the power sector, fossil fuel use (particularly coal) is declining. This is being partly replaced by decentralised and intermittent renewables.[551]
- Digitisation. Ageing networks and computing infrastructure need upgrading, and will increasingly use data-intensive and automated processes to make the system work more efficiently.

These factors, combined with an expected increase in the use of electricity to supply heating and transport, are spurring the development of 'smart grids' and 'flexible electricity systems' (POSTnote 587).[552,553,554] Flexible technologies include electricity storage, interconnection with overseas electricity grids, and 'demand-side' flexibility (which consists of a number of processes that allow residential or commercial consumers to alter their level of demand at different times).[555,556] Smart grids broadly encompass the control, monitoring and processing technologies that allow networks to respond to and manage complex power flows arising from flexibility.[554] Although most flexible and smart grid technologies already exist, in many cases the cost of deploying and operating them are high compared to more established technologies.

Changing power production will be further affected by new forms of electric mobility. Electric vehicles (EVs), driven by rapid improvements in cost and performance of battery technologies, are emerging as an alternative to conventional petrol and diesel vehicles.[557] If demand for EVs increases as expected, electricity network operators and policy-makers will need to manage the additional demand for charging consumer vehicles through 'smart charging' and 'vehicle-to-grid' technology.[556,558] These provide flexibility by automating charging or using the EV battery as a store from which to supply the grid at times of peak demand. A further source of power demand increase may arise from heating, for example in buildings and industry. In the UK, a substantial proportion of heat arises from natural gas supplied by the national network. Decarbonising heat is likely to be a particular challenge, as all technology options for doing so – electrification, using heat pumps, district heat networks using combined heat and power or renewable heat, or hydrogen within the gas network – entail significant costs, complexities and, in many cases, potential disruption for consumers.[483,546] While electrified and district heating systems are widely used across the UK and internationally, hydrogen has yet to be implemented at scale for this purpose.

Implications and challenges

- Achieving the scale and scope of decarbonisation implied by the UK's long-term emissions targets is dependent upon key low-carbon technology developments in the next decade.[5] This includes substantially expanding power generation from renewables, deploying and demonstrating technologies such as carbon capture and storage (CCS), and achieving further cost reductions in storage technologies.[559,560]

- There are potential risks to energy security from energy system change. Although a lower import dependence following potential reductions in natural gas use may be favourable from an economic or political standpoint, such a situation is not guaranteed (gas use may decline, remain constant or increase). Potential challenges also exist in meeting daily peak electricity or heat demand if a greater proportion of intermittent or variable power is used without sufficient flexibility in place.

- All heat decarbonisation pathways are likely to entail substantial costs and change for some consumers. In addition, changes to complex systems, such as the gas network, would require government support for new infrastructure, co-ordination across multiple bodies, and new regulatory systems or powers.[546]

- Industry is a particularly challenging sector to decarbonise because of its demand for high-temperature heat, the complexity and diversity of the sector, and its interlinked global supply chains.[561] The Committee on Climate Change suggests that to meet its net zero emissions pathway by 2050, substantial emissions reductions will need to be achieved using Carbon Capture and Storage, together with improvements in energy and resource efficiency and other processes. This will require immediate action and a strong supportive policy framework.[560]

Key unknowns

- Developments in the cost of commodities (e.g. natural gas), as well as of low-carbon energy technologies, will fundamentally affect the future energy system. However, the drivers of costs are complex. They depend upon a number of successive uncertain developments.

- There are substantial uncertainties around the costs, technical feasibility and social acceptability of hydrogen-based heating systems. Lessons will need to be drawn from trials and pilot projects in the UK undertaken in the short- to medium-term if the technology is to contribute significantly to 2050 decarbonisation objectives.

- The future level of UK commitment to emissions reductions will have a substantial effect upon future energy systems. Although mitigation ambition is expected to strengthen in coming years to meet the UK’s long-term emissions targets, there is a political risk that future administrations could de-prioritise ambition as a result of wider landscape policy changes, such as withdrawal from the European Union.

TECHNOLOGICAL ADVANCES

The digital divide Internet governance Emerging computing technologies Trends in transport technologies Applications of genome editing Collaborative research


61 %
Dienstag, 10. Januar

THE DIGITAL DIVIDE

The capacity and performance of digital technology is improving, and an increasing number of devices are able to connect to the internet. By 2050, the number of internet-connected things is projected to grow to about 50 billion devices.[562] This has brought benefits to individuals and communities through easier communication and access to information, and greater convenience.[563] However, these effects are not evenly distributed both within and between countries, which can limit economic opportunity, social and cultural exchange, public services, and democratic empowerment. Policies and practices pursued at individual, organisational and national levels can shape the extent of the digital divide and the groups they affect.

Overview of area

Digital technologies offer many potential benefits from accelerating economic growth and increasing productivity, to facilitating social inclusion and tackling social challenges such as increasing trust and participation in democratic processes.[564,565,566] The benefits of digital technologies are not experienced equally however, and over half of the population globally remains offline.[567] Furthermore, UN data suggest that internet user growth declined from 17% in 2007 to 5.5% in 2018.[568] The concept of the digital divide can include access to the internet, 'operational' skills to be able to use it appropriately, and the ability to use it to result in beneficial outcomes.[569,567] The factors that have the most influence on the extent of the digital divide are sociodemographic (such as age and gender) and socioeconomic (such as employment status).[569] Some stakeholders, including the UK Government, have expressed concerns about the future challenges faced by digitally excluded people, particularly around employment.[570,571] For example, in 2016 it was estimated that in the next 10–20 years, 90% of jobs will require some sort of digital skills.[572] Other research suggests that acquiring digital skills improves earnings by 3%–10%.[572]

In the UK, research carried out by Lloyd's Bank, which involved face-to-face interviews with 4,000 bank customers, found that, although the number of people lacking digital skills is declining, 8% have no basic digital skills, and 19% cannot carry out a full set of seven basic digital tasks (including connecting a device to a WiFi network and opening an internet browser to find and use websites).[573] There are several factors that influence the UK's digital divide, such as age and whether a person has a disability.[573] For example, adults aged over 65 years make up the largest proportion of non-internet users[574,575] and people with a disability are 2.4 times more likely to not use the internet than those without a disability.[573] There is also regional variation in digital skills across the UK, with the North West and East of England having the largest proportions of people without any digital skills.[573] A 2018 survey of 992 people on behalf of Broadband UK found that for those who do not use the internet, the main reason is a perceived lack of need or desire to use it (83%).[576] Other barriers cited by respondents included: a lack of digital skills and/or knowledge (22%), not having an internet connection and/or device to be able to access the internet (18%), and equipment and services being too expensive or not worth the money (12%).[576] Educating older people and building their confidence in using digital technologies is being explored as a way to narrow the digital divide.[577] For example, Age UK has run a series of pop-up stalls across the UK to demonstrate to older people the range of resources that can be accessed on the internet (for example old films, music and local photos).[578]

A recent UN report found that the world's least developed countries are narrowing the 'digital divide,' with millions of people now taking advantage of smart phones and other digital devices.[579] Successful examples include mobile money services such as M-Pesa, which help people without bank accounts to make payments electronically by allowing them to deposit money and make transactions via a mobile app. This was launched in 2007 by Safaricom in Kenya, and is now available in the Democratic Republic of the Congo (DRC), Tanzania, Mozambique and Lesotho.[580] These technologies have been shown to have long-term effects on poverty reduction and employment opportunities, and to reduce gender and other inequalities.[581] A 2015 survey by the think tank the Pew Research Center shows an increase in the percentage of people in emerging and developing countries that reported using the internet at least occasionally or owning a smartphone, from a median of 45% across 21 countries in 2013, to 54% in 2015.[582]

In 2016 it was estimated that the digital skills gap in the UK cost the economy £63 billion a year in lost GDP.

A key question is how individuals, organisations and countries adapt to digital technologies.[583,584] Advances in mobile broadband (such as 5G) are expected to make the delivery of digital services quicker and more reliable.[585] The UK Government is supporting the roll-out of superfast broadband to areas that are not reached by private investment and has set a target to deliver a nationwide fibre-to-the-premises network (the infrastructure that underpins high speed broadband connections to premises) by 2033.[586] In some countries, technological initiatives have been launched to try and increase internet access. For example, in response to limited access to high-speed internet in India, a more affordable 4G JioPhone was developed, which has increased internet access.[587] In 2015, Facebook launched an app called 'Free Basics' which provides users in the developing world with access to a small selection of websites without the need to pay for mobile data. However, the app has been criticised for not catering to the language needs of its users and for featuring very little relevant content.[588,589]

Implications and challenges

- The digital divide can have impacts on economies, education, employment and society. For example, in 2016 it was estimated that the digital skills gap in the UK cost the economy £63 billion a year in lost GDP.[590]

- It can be difficult to get an accurate picture of the scale of the issue within and between countries, as measurement is difficult and the data available vary across countries.[591,592]

- The digital divide does not affect people equally and impacts are therefore likely to be experienced differently depending on a variety of factors, including an individual's age and socioeconomic status.

- Access to services (including government services) is increasingly moving online. For example, the UK Government's 'Making Tax Digital' initiative requires people to fill out their tax returns using an online portal.[593] This raises challenges about how digitally excluded people can continue to be catered for.[594]

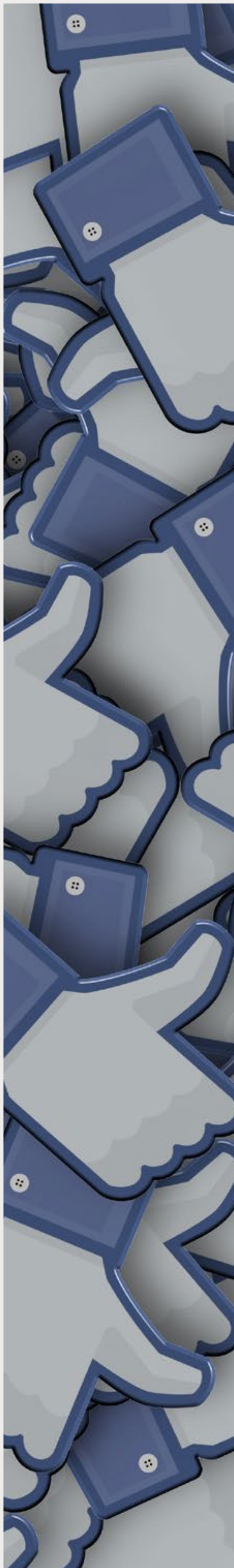
Key unknowns

- Policy and regulatory responses to the digital divide will depend on available resources and political will. These are likely to vary significantly between countries and over time.

- There is limited evidence about effective approaches to address the issue of digital divide.

- It is unclear when the UK will achieve its goal to deliver out fibre to the premises across the UK and what unforeseen challenges may emerge during roll-out. Political leaders from 20 towns and cities across the North of England have recently written to Ofcom to call for fibre operators to take a more coordinated approach to fibre roll-out to avoid issues such as duplication of investment and disruption from street works.[595]

INTERNET GOVERNANCE



The internet has been described by the Government as a "powerful force for good", but it also brings new challenges relating to illegal, harmful or inappropriate content.[596,597] There is ongoing debate about if and how the internet should be governed, and different states have conflicting views on internet regulation. Increasingly, there have been calls for technology companies to take a more active role in the identification and removal of illegal content from the internet.[598,599,600] The UK Government's 2019 Online Harms White Paper outlined plans to introduce a new statutory duty of care for companies, which would be overseen by an independent regulator.[601]

Overview of area

The internet has become an integral part of life in the information age, with over 4.1 billion users around the world.[602] It has enabled the global free flow of information, bringing many advantages, including widening access, better communication and greater economic opportunities. [603,604,605] Over the last decade, competing visions of how the internet should be governed have emerged. Growing disagreement has been attributed to several factors, including a greater number of parties being involved in internet governance (for example emerging powers such as Russia and China) and tensions between governments and multinational companies.[606] A number of stakeholders have suggested that this may lead to internet 'fragmentation' – the idea that the internet may split up in order to separate networks that are controlled and regulated by different states or groups of states.[607,608] Some commentators have argued that diverging regulatory regimes have already started to cause the internet to fragment.[605,609,610] The Chinese Government implements different technologies to block access to some content and websites (including most Google-owned services, Facebook and Twitter),[611] and has developed its own tools for web browsing, social networking and online shopping.[612] China's social networking site WeChat was reported to have removed articles about the US-China trade war and US sanctions against Chinese telecoms company ZTE.[613] More recently, China has imposed new regulations on short videos, identifying 100 categories of banned content (such as content that mocks the national anthem).[614,615] Russia has also moved towards increased internet oversight. In July 2017, it passed legislation prohibiting the use of internet proxy services and virtual private networks (VPNs).[616]

Another aspect to the debate on protecting the free flow of information online is 'net neutrality', which is the principle that Internet Service Providers (ISPs, companies that provide internet access to homes or businesses) should treat all online content with equal priority.[617] There has been increasing concern among content providers, such as Amazon and Netflix, that ISPs may choose to prioritise certain data by transmitting it more quickly or at higher quality, to the detriment of competitors' content.[618,619] Advocates of net neutrality argue that keeping the internet an open playing field is important for innovation and for providing an open platform for freedom of speech.[620] The UK adopted net neutrality safeguards for the equal treatment of internet traffic through the EU Regulation on Open Internet Access in 2016. However, in the US in 2018, the Federal Communications Commission (FCC) repealed net neutrality safeguard policies that had been in place since 2015.[621] A bill intended to restore these net neutrality rules will be considered by the US Senate later this year.[622]

Increasing public concern about online harms has led to greater pressure on companies to take responsibility for content on their online platforms, and increasing calls for government action.[597,623,624,625,626] In particular, many groups have expressed concerns about the potential negative impacts of social media on children's mental health.[627] Social media providers implemented a range of measures to regulate their platforms in 2018, including features to reduce fake news content, account suspensions for abusive users, and a ban on sites hosting blueprints for 3D-printed guns.[628,629,630] The Chinese video games producer Tencent also introduced measures that aim to restrict children's' video games usage.[631] However, many experts have argued that self-regulation has not been a successful approach to tackling online harms, as voluntary action has not been applied consistently. The UK Government plans to introduce a new statutory duty of care, overseen by an independent regulator, to ensure companies take more responsibility for the safety of their users. Companies will face fines and potential legal action for non-compliance. While this is widely seen as a positive step, some commentators argue that any efforts to control online content may have negative impacts on the free flow of information, innovation and competition, and human rights such as freedom of expression.[632,633,634,635] In addition to the proposed duty of care, the UK's Data Protection Act 2018 requires the Information Commissioner to produce an 'age-appropriate design code', which sets design standards for online services likely to be used by children.[636] This code is currently under consultation. Internationally, parliamentarians from nine countries (including the UK) have signed a declaration on the 'Principles of the Law Governing the Internet', which affirmed their commitment to transparency, accountability and the protection of representative democracy in regard to the internet.[637]

Conflicting visions of how the internet should be governed, create the potential for the internet to be divided into separate smaller networks.

Concerns have been expressed about the internet being increasingly used as a political tool.[597] One particular area of concern is the use of data analytics in political campaigns via social media. In the UK, the Information Commissioner's Office (ICO) recently launched an investigation into the activities of the company Mainstream Network, a pro-Brexit website promoted via Facebook, which encouraged people to lobby their MPs.[638] The ICO is investigating whether the company's activities breached EU General Data Protection Regulations.[639] While political advertising on television is regulated and overseen by Ofcom,[640] political advertising on social media remains unregulated. A number of bodies have called for this to change; following its Inquiry into disinformation and fake news, the House of Commons Digital, Culture, Media & Sport Committee recommended that there should be complete transparency around online political campaigning,[641] and the Electoral Commission has called for improved transparency about how online campaigns are funded.[642] A further concern is about the production and online dissemination of convincing fake videos and images known as 'deepfakes', usually created by superimposing images of people on to other images.[643] So far, deepfake technology has been used to create altered pornographic clips featuring celebrity faces and has been used to misrepresent well-known politicians.[644] For example, a Belgian political party created a fake video of the US President offering advice on climate change.[645] This raises concerns about how the internet can be used alongside sophisticated AI to undermine public trust in political systems.[646] To tackle this problem, the US Defense Advanced Research Projects Agency (DARPA) has funded development of AI software to detect when videos have been altered.[647] One of the issues around using AI to detect or filter online content is the potential for algorithmic bias (see area of change 'Emerging Computing Technologies').[648,649]

Implications and challenges

- Conflicting visions of how the internet should be governed create the potential for the internet to be divided into separate smaller networks, which could raise future challenges around the movement of data and economic growth.[650]
- Future decisions about internet regulation will need to take into account the greater calls for action to tackle illegal, harmful and inappropriate online content, but also opposing concerns about the impact of regulation on freedom of speech, free flow of information and innovation.
- There may be challenges around the implications of deepfakes and how they are used. As AI becomes more sophisticated, the challenge of detecting and removing deepfakes is expected to grow.[651]
- With more countries realising the social and economic benefits of the internet,[652] there may be increased potential for the internet to be used by countries as a means of furthering their interests internationally.[653]
- There have been calls for greater transparency and accountability of algorithms used to manage online content.[601,654]

Key unknowns

- It is unclear what regulatory models different states will adopt in the future and the implications of these on future trade, e-commerce, data movement, access to content and innovation.[655]
- It is not yet clear which companies will be subject to proposed UK Online Harms regulation, and exactly what the proposed duty of care will require of them.
- Due to the rapid pace of development in digital technologies, it is not clear whether interventions designed in the present day will continue to be fit-for-purpose.[599] Some commentators have noted that regulations will need to keep pace with rapid technological advances.[656]

EMERGING COMPUTING TECHNOLOGIES

Developments in computing technologies, such as artificial intelligence (AI), immersive technologies and quantum computing, are expected to have significant social and economic impacts. Potential benefits include more powerful tools for innovation and problem solving, more efficient management of infrastructure and resources, and new products and services that could enhance people's quality of life. These technologies also have the potential to disrupt many aspects of life, from employment to security, and raise new challenges, including for transparency, accessibility, fairness and governance.

Overview of area

Computing technologies are increasingly shaping the way that we work, study, socialise, shop and access services. Innovations in software, hardware and networks are enhancing our ability to collect, store, share and analyse data. They have the potential to increase productivity, improve efficiency, and lead to the creation of new products and services.[657] Advances in AI software, particularly machine learning (that allows computers to learn from examples or experience),[658] are leading to more widespread use of AI across a variety of sectors. Machine learning has rapidly improved voice and image recognition, enabling AI systems to perform tasks ranging from verifying the identity of a telephone banking customer based on their voice,[659,660] to assisting in disease diagnosis by rapidly identifying abnormalities in medical images.[661,662,663] In transport, AI is increasingly being deployed in traffic management systems and driver-assistance functions (such as parking assistance).[664,665] In recruitment,[666] some companies are using AI tools to screen candidates.[667] AI may also increasingly be used for malicious purposes, such as cyber-attacks, or the creation of convincing fake videos and images known as 'deepfakes' (see the 'New Directions in Cyber Security' and 'Internet Governance' areas of change).

Advances in computer hardware are also pushing back the boundaries of conventional computing. Quantum computers, which process data by exploiting the quantum behaviour that matter and light display at very small scales,[668] could significantly reduce the time it takes to solve certain types of problem, enabling them to tackle tasks that would take conventional computers millions of years to complete.[669] Prospective uses of quantum computing include aiding drug discovery by improving predictions about the properties of new drugs; finding the optimal approach in a given situation, such as the most efficient combination of routes for a fleet of delivery vehicles; and speeding up searches of certain large unsorted datasets.[670,671] Small-scale quantum computers capable of undertaking specific tasks already exist. In January 2019, IBM launched a 20 qubit quantum computer designed for commercial use outside of the laboratory.[672] However opinions vary on when, or if, a 'universal' quantum computer with the flexibility to run any quantum algorithm will be developed.[673,674,675,676,677,678,679] The UK Government committed £75 million in the 2018 Autumn Budget to a new National Quantum Computing Centre,[680,681] which aims to develop the world's first universal quantum computer.[682] The early 2020s are likely to be a critical period for the development of quantum computers, when applications and revenues will need to emerge in order to drive future investment in the field.[683]

The automation of complex tasks could increase UK labour productivity by 25% by 2035.

Innovations in hardware may also emerge from fields such as neuromorphic computing that aims to replicate characteristics of the human brain using technologies that copy the morphology of individual neurons.[684] If successful, this could lead to more efficient computer systems that are able to learn, reason and support human decision-making, using significantly less energy than current systems. Such systems would have many potential applications, such as recognising images or detecting smells. Other developments in hardware are likely to relate to improvements in the way that electronic components are made, potentially enabling smaller, faster and more complex devices. One new technique uses a novel printing process to create advanced circuit boards that are smaller and less prone to overheating.[685] New innovations in hardware may also be achieved by creating novel computer architectures using conventional technologies. For example, Google has created a TPU (Tensor Processing Unit) chip designed specifically to speed up machine learning calculations.[686,687]

The trend for increasing numbers of devices to be connected to the internet (forming an 'Internet of Things') is likely to continue, driven in part by new capabilities across a number of areas.[688,689] New sensor technologies may make it possible to convert everyday items in to 'smart' devices. For example, researchers have developed small, thin electric circuits that can be stuck onto objects, enabling them to sense their environment and to communicate with other devices.[690] Developments in wireless communications technologies, such as 5G, are expected to enable high speed, high capacity and low latency (more responsive) data transfer.[691] This will support applications across a number of different sectors, including transport, where 5G networks may in the future enable vehicles to communicate with each other and nearby road infrastructure.[692] Processor design company, ARM, predicts that 1 trillion devices will become connected to networks over the next few decades.[693] New approaches to system design and the distribution of processing power and storage across networks will be required to handle the workloads that these devices create. One possible approach is edge computing, which involves processing data near to the devices that collect them instead of sending all of the raw data to a centralised location for processing.[694] This may also help to address certain concerns relating to cyber security and data protection, as more data are stored and processed locally.

No concrete ethical framework currently exists to guide those involved in the development of AI.

The way that people interact with computers is also evolving, as immersive technologies (computer-generated environments that a user can interact with in a seemingly real way) become more widely available. These include virtual reality (a completely simulated three-dimensional image), augmented reality (that layers computer generated images on to an image of the real world) and haptic technologies (that use sensors to recreate the sense of touch by applying forces to the user).[695] The gaming industry is a major driver of developments in immersive technology, but interest is growing in other applications. Immersive technologies are being used to simulate hazardous situations in a controlled environment, for example in the training of police officers, forklift drivers, and oil and gas rig workers.[696,697] In healthcare, virtual reality can help patients recover from post-traumatic stress disorder and can help patients undergoing physical therapy.[698] Immersive technologies may also be used in combination with AI to create personalised experiences, for example, customised virtual reality education or training courses.[699,700] Other novel ways in which people can interact with computers includes brain-computer interfaces. These use signals recorded from the brain to enable a person to interact with a computer.[701,702] Such technology can enable communication and physical control in people with disabilities, for example forms of paralysis. They might also be used to enhance performance in non-disabled individuals and could lead to concerns relating to inequality, consent, privacy and security (such as the potential for hacking).[703,704]

Developments in computing technologies are changing the way that we collect and use data, giving rise to new ethical, social and economic challenges.[705,706,707] Concerns have been raised globally about the potential for technologies such as AI and robotics to displace people from jobs (see 'Work and Employment' area of change). 'Social scoring' schemes are being piloted in China, whereby citizens are rewarded or penalised based on data about their behaviour, which has led to worries that such schemes may have the potential to be used to limit free speech and other civil rights.[708,709] Concerns have also been raised that the introduction of different regulatory regimes in different geographical regions may restrict the free flow of data, potentially leading to negative economic effects (See 'Internet Governance' area of change).[710] Moves are being made towards developing governance frameworks for data and digital technologies. The UK Government recently established a Centre for Data Ethics and Innovation to advise on how the UK should govern the use of data and data-enabled technologies.[711] The Centre is part of a wider programme of work being delivered under the Industrial Strategy, which includes an AI Sector Deal investment package of up to £0.9 billion from government and industry to support the development of the UK's AI sector.[712]

Implications and challenges

- AI has the potential to bring considerable social and economic benefits,[713] with one study estimating that the automation of complex tasks could increase UK labour productivity by 25% by 2035.[714]

- Greater use of AI is likely to impact the UK labour market by both displacing and creating jobs. Analysis by PwC has suggested that 30% of UK jobs could be at high risk of automation by 2030, but that the net long term effect will be neutral, with AI creating as many jobs as it displaces.[715] It has been suggested that job losses could differ between regions and different social and demographic groups, which may increase inequality.[716,717]

- There are concerns over the malicious use of AI. For example, it may be used to facilitate cybercrime and produce fake news content to undermine public trust in the media and political institutions.[718]

- AI systems can pose challenges for ensuring transparency, accountability and the appropriate attribution of liability for decisions they make or inform, as it is not always possible to explain how they have reached a particular outcome.[719] AI systems can also be susceptible to introducing or perpetuating bias.[720] Experts have warned that a lack of public trust in AI may be a barrier to the adoption of these technologies.[721]

- There is disagreement about the adequacy of existing legislation in the event that AI systems fail or make erroneous decisions that cause harm.[722]

- No concrete ethical framework currently exists to guide those involved in the development of AI.[723]

- Quantum computing could unlock computing power that is superior to conventional computers but may have the potential to break widely used encryption protocols, which could lead to the misuse of sensitive financial, identity or national security data.[724]

- Neuromorphic computing might lead to more energy-efficient computer systems, able to learn, reason and support human decision-making.[725]

- Nesta estimates that there are 1,000 companies specialising in immersive technologies in the UK, employing around 4,500 people and generating £660 million in sales.[726] PwC predicts the rapid growth of interactive video content through virtual reality and video games over the next 5 years, and has forecast that over 16 million virtual reality headsets could be in use in the UK by 2021.[727]

- Immersive technologies may create potential challenges for security, privacy and safety, for example if a hacker were able to take control of an augmented reality headset.[728]

- There may be barriers to accessing new computing technologies, for example if only large corporations and governments have the resources to develop or buy them. Some suggest that unequal access to technologies may cement or increase power imbalances between nations, or between these powerful actors and citizens.[729]

- The development, implementation and use of emerging computing technologies will require a workforce with a range of skills. Accenture estimates that the UK might miss out on as much as £140 billion of GDP growth over the next 10 years, as a result of the UK's digital skills gap.[730]

Key unknowns

- Evidence for the impact of automation technologies on jobs is limited and predictions are difficult because of uncertainties in the rates of technological development and adoption, as well as other factors that may affect employment, such as changes to the wider economy.[731]

- Although some of the potential risks posed by AI and other computing technologies are already apparent, many are still unknown, and it is not clear if and how they will need to be regulated.

- It is currently unclear how rapidly quantum computing, neuromorphic computing and other nascent technologies will develop, or what their main applications will be.
- It is unclear how widely these new technologies will be adopted, what the scale of their benefits will be, and how equally those benefits will be distributed across society.

TRENDS IN TRANSPORT TECHNOLOGIES

A major trend across road, rail and air transport is the move towards greater levels of automation and connectivity between vehicles and infrastructure. Increased automation and improved rail signalling could lead to greater capacity on the railways and more efficient services. Many countries are now trialling connected and autonomous vehicles on public roads,[732] however, their use is not widespread and significant safety, liability and cyber security challenges remain. Aerial drones (unmanned flying vehicles) are being developed to transport goods but will require new approaches to airspace management if deployed on a large-scale. Other key trends include the development of new models of transport provision with increasing personalisation, such as 'Mobility as a Service', and increasing electrification driven by efforts to reduce greenhouse gas emissions. More speculative modes of transport in the early stages of development include hyperloops and passenger drones.

Overview of area

Over the next two decades, vehicles are likely to continue to become increasingly connected and autonomous.[733,734,735] Connectivity and automation are to some degree, already well-established in parts of the transport sector. For example, automated train operation has been used on the Docklands Light Railway since 1987.[736] Mainline railways are likely to see higher levels of automation and connectivity in the future. In 2018, the UK Government published the 'Digital Railway' strategy, setting out plans to modernise UK railway infrastructure.[737] It included the implementation of digital signalling, rail traffic management technologies and automatic train operation to increase railway capacity and reduce journey times, among other intended benefits.[738] A self-driving mainline train carried commuters between St Pancras and Blackfriars Stations in London for the first time in March 2018.[739]

Most modern aeroplanes include automated systems.[740,741,742] Two recent crashes of Boeing 737 MAX planes, which initial investigations suggest may have been linked to an automated stall-prevention system, have renewed discussion about some of the potential challenges associated with automation.[743,744] These include ensuring pilots have adequate understanding of automated systems and are able to take manual control when needed. Automation technologies are being deployed in other types of aerial vehicle. Aerial drones are being developed to deliver, for example, goods from retailers to homes or medical samples between hospitals.[745]

Road vehicles are also becoming increasingly automated and connected, for both passenger and freight applications. Many modern cars are already capable of some level of connectivity or automation, for example automatic braking, lane control and parking assistance.[746] However, established automotive manufacturers and start-up companies are developing connected and autonomous vehicles (CAVs) that can perform the full range of driving operations without human intervention. Trials of CAVs are already taking place on public roads. In the US, company Drive.ai is running a self-driving car shuttle service in Texas that operates in a specific fenced region.[747] Waymo, which began as a Google project, has trialled automated minivans in Arizona without a safety operator on board.[748] In the UK, the Government has identified CAVs as a key technology in its Industrial Strategy[749] and announced a £250m investment in the development and deployment of CAVs as part of its Automotive Sector Deal.[750] It also recently published a code of practice to support the testing of CAVs on UK roads.[751] The Centre for Connected and Autonomous Vehicles is supporting projects to trial CAVs in locations that include Milton Keynes, Bristol, London and Coventry.[752,753] In the freight industry, there is emerging interest in truck platooning. This involves multiple trucks that are wirelessly connected and travelling in convoy, with a lead driver that makes decisions on behalf of the trucks behind, improving fuel efficiency and road congestion.[754]

Historically, new technologies tend to be initially expensive and only become accessible to more of the population as prices fall.

Meanwhile, 'mobility as a service' may have the potential to provide more personalised transport services, improve air quality, and increase the efficiency of transport networks.[755,756,757] This is a concept whereby consumers use a digital platform (usually a smartphone or web application) to access different transport modes through a single system that integrates planning, booking and paying for travel. This is a relatively new idea, and the cost and feasibility of scaling such business models are currently unclear.[758,759] A key question will be whether users want to move away from an ownership-based transport model towards a service-based one.[760] Trends indicate that private car ownership has gradually decreased among young people over the past ten years, with an increase in the number of people using ride-sharing services, such as Uber and Lyft.[761]

Targets to reduce greenhouse gas emissions are helping to shape the development of technologies across road, rail and air transport. The Government Office for Science recently predicted that electrification will increase sharply from the mid-2020s, as battery technology improves, lower taxes drive adoption, and charging infrastructure for electric road vehicles becomes more widely available.[762] Alternative fuels are also under development, such as hydrogen.[763]

In the longer term, proposed future transport technologies include 'hyperloops' (whereby passengers travel at high speeds in capsules that move along a tube under partial vacuum)[764,765] and 'passenger drones' capable of carrying people, for example as urban taxi services or air ambulances.[766] These technologies are in the very early stages of development and are likely to face significant regulatory, safety and implementation challenges. A number of hyperloop feasibility studies are underway in the US and elsewhere,[767,768,769] while Rolls-Royce has announced plans for an airborne electric vehicle capable of vertical take-off and landing that could, in principle, carry five passengers.[770,771]

Implications and challenges

- CAVs could have benefits for safety, traffic management and the environment, and could improve mobility for older people and people with disabilities.[772] One estimate suggests that the UK market for CAVs might reach £28 million by 2035.[773]

- PwC estimate that the adoption of aerial drones might be worth £16 billion to the UK by 2030.[774]

- Wide-spread deployment of both CAVs and aerial drones, is likely to require the development of new technologies, regulations, standards and tests.[775,776]

- There are multiple challenges associated with the increasing levels of connectivity and automation in the transport sector. These include: the need for new infrastructure, which is likely to require significant levels of research and investment; establishing new insurance and liability frameworks; [777,] and the potential vulnerability of interconnected transport systems to cyber-attacks.[778]

- Autonomous cars raise ethical questions. For example, how to balance the safety of passengers with that of cyclists or pedestrians, or how to trade-off travel efficiency against environmental impact.[779,780,781]

- Connected transport systems that involve data collection present an opportunity to better understand and meet demand, but also raise challenges for data protection and privacy.

- Excessive use of drones and other new modes of air transport could create noise and crowd skylines.[782]

- Future applications of CAVs and aerial drones are likely to be shaped significantly by public opinion, consumer attitudes and regulation.[783,784]

- Large-scale uptake of electric road vehicles will require sufficient electricity grid capacity and the deployment of charging infrastructure.[785] Electric vehicles may present challenges for the safety of pedestrians and cyclists, as they are much quieter than non-electric cars at low speeds. They might also lead to a decrease in government tax revenues.

- Successfully managing the transition from current technologies to new technologies will be a key challenge for the transport sector. For example, ensuring that autonomous road vehicles that do not have a human driver can operate alongside vehicles that do.[786]

- New transport technologies may not be equally accessible to everyone. Historically, new technologies tend to be initially expensive and only become accessible to more of the population as prices fall.[787] The rate at which technologies will be adopted is difficult to predict.

- A skilled workforce will be required to create and implement new technologies.[788]

Key unknowns

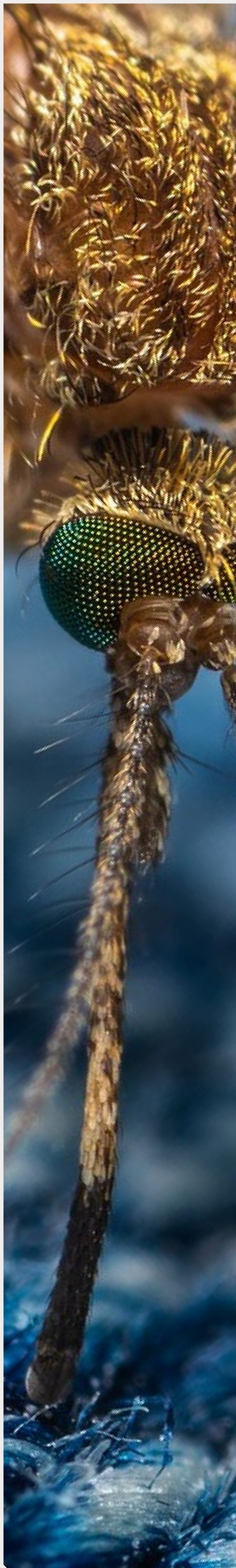
- It is unclear how connected and autonomous transport will change existing roles in the transport sector and what new job opportunities may be created. Some stakeholders have highlighted that certain roles may be at risk, such as freight lorry drivers, taxi drivers and train drivers.[789]

- There are unknowns relating to the infrastructure and technologies needed to support a connected transport system, such as how much they will cost and where funding will come from. The RAC highlighted that very little research has been done on the readiness of the UK's road infrastructure for connected and autonomous vehicles.[790]

- Some predictions suggest that fully autonomous passenger cars will be in widespread use on UK roads by 2040, however there are uncertainties related to the timeframes for developing these vehicles and the way in which they will be implemented.[791,792,793]

- The feasibility and timescales for more speculative technologies, such as passenger drones, are also unknown.

APPLICATIONS OF GENOME EDITING



Making selected changes to DNA sequences can confer new characteristics (traits) to an organism. Such changes can occur spontaneously (mutations) or as a result of interventions by researchers. Early attempts to improve crop varieties by making changes to DNA sequences involved the use of chemicals or high energy radiation to increase the rate at which mutations occur. While these methods produce entirely random changes to an organism's DNA, they have resulted in many improved crop varieties. Since the late 1980s and early 1990s, genetic modification (GM) techniques have been widely used in plant breeding to introduce new gene sequences into commercial crop varieties to confer traits such as resistance to herbicides and pests. These early GM techniques are inefficient because researchers have little control over where in an organism's existing DNA (genome) the new sequence will be incorporated. Genome editing refers to several novel techniques that allow researchers to specify the exact point (or points) in a genome that they wish to modify. These techniques can be used to: a) make point mutations at a specified site on the genome, b) delete whole gene sequences between two specified points on the genome, and c) insert new DNA sequences at a specified point in the genome.

Overview of area

There are several different genome editing techniques – TALENS and CRISPR-Cas9 are the two most widely used. All consist of guide sequences (that specify where the change is to be made) tagged onto an enzyme that can snip double-stranded DNA along with a new gene sequence (if the aim is to incorporate a new gene or genes into the host). There are three main areas of application for genome editing:

Gene drives, which can be used to spread a gene rapidly through a population. To date the main interest has been in using CRISPR-Cas9 to spread a deleterious gene (one that causes death or sterility) rapidly through populations of insect vectors, such as mosquitoes, that transmit human infectious agents, such as malarial parasites, and dengue or Zika viruses. In laboratory trials, over 95% uptake of a gene has been achieved within five generations. The techniques only work with organisms that multiply sexually,[794] and works best in organisms that multiply very rapidly.[795]

Human therapy. There are two possible approaches here. The first involves genome editing of somatic cells (cells that are not stem cells, embryos, sperm, eggs, or their precursor cells) for use in therapy to treat a genetic condition. The success of these treatments largely depends upon delivering enough modified cells to the appropriate part of the body for long enough to have a therapeutic effect. In practice, the main applications to date have been for the treatment of blood cancers, such as certain types of leukaemia and lymphomas. The second possible application is to use genome editing in human germ cells (embryos, eggs and sperm) to avoid serious genetic diseases. While such procedures are prohibited in many countries, in November 2018 a Chinese researcher was reported to have used genome editing on two human embryos in an attempt to make the resulting twin girls resistant to HIV infection. The research has yet to be confirmed through peer-reviewed channels.

Modification of plants and animals. GM techniques and mutagenesis have been widely used in crop breeding programmes to introduce desirable traits, such as high yield,[796,797] and pest and herbicide resistance. GM and genome-edited animals are widely used in medical research, for example as models of human disorders.

Implications and challenges

The main challenges raised by genome editing include:

- Ethical considerations. Genome editing used in somatic cell therapy in humans has therapeutic potential for the individual being treated. All such applications require approval from a research ethics committee that will weigh the potential risks and benefits to the patient. The use of genome editing in germline (eggs, sperm and embryos) cells raises wider ethical issues because any changes made may be inherited by future generations. There is widespread consensus that such practices would be ethically unacceptable and the (unconfirmed) announcement by a Chinese researcher that this technique has already been used has caused widespread adverse reactions.

- Environmental considerations. These particularly apply to gene drive applications and potentially also to genome edited crops. With gene drive, the main concern is the unknown consequences on ecosystems of removing a species from an area, particularly given that there is no proven way of reversing the gene drive. For genome edited crops, the main concern would be the possibility of gene flow between the crops and close wild relatives (for example wild grasses acquiring insect resistance).

- Safety. This is a potential concern for the use of genome editing in human therapy.[798] Although genome editing is designed to be highly targeted to specified locations of a genome, the most widely used technique (CRISPR-Cas9) is known to also make changes at other, non-specified sites (off-target effects), in some cases. If these occurred during human germline therapy they could cause unintended changes that would be inherited by future generations.

- Regulatory considerations. A key question here is whether existing GM rules apply to genome edited organisms.[799] While the European Commission has yet to decide on this issue, a ruling by the European Court of Justice (ECJ) in 2018 stated that existing GM regulations would apply to the products of genome editing, even where such techniques are used for making targeted mutations. Since such mutations can also occur spontaneously, it is not clear how this ruling will be enforced. The European Commission's Group of Chief Scientific Advisors has recommended revising existing GM regulations to reflect current knowledge and scientific evidence, in particular on gene editing and established GM techniques.[800]

- Animal welfare. There are concerns that genome editing of livestock could be detrimental to animal welfare. For example, the EU has been in a trade dispute with the US over hormone implants used in the American dairy sector to improve yield. Such improvements could potentially be achieved by genome editing, but the EU concerns focus on animal welfare (for example, the increased risk of mastitis in dairy cattle).

Key unknowns

- It is not clear whether the EU will revise its regulations on genome editing and GM products to reflect the ECJ ruling. It is also not clear whether the UK will align its regulation of genome editing/GM with that of the EU post-Brexit.

- The acceptability of genome edited products to the wider public – will they be better received than GM products?

- Whether the current consensus against using genome editing for human germline therapy will hold or will be overtaken by the pace of technological advance.

- Whether genome editing (particularly CRISPR-Cas9) techniques will prove to be safe and reliable enough to use in human therapy.

- What the environmental consequences might be for using a gene drive to control insect vectors and how that gene drive might be reversed should things go wrong.

COLLABORATIVE RESEARCH

The benefits of collaborative research have long-been recognised. In the social sciences, a model of calling for greater overlap between narrow disciplinary clusters was proposed as long ago as the 1960s.[801] Since this time, the benefits of collaborative working have become more widely apparent across all scientific disciplines. Collaboration can operate at different levels, between laboratories in the same research programme, or between researchers in entirely different disciplines. Either way, it helps a wider range of perspectives to an area of science and often results in generating unforeseen avenues of research along the way. Encouraging collaborative research has been one of the core principles of EU research funding and there are concerns that the UK science base may suffer if it no longer has access to EU funding post-Brexit.[802]

Overview of area

Collaborative research can serve several purposes:

- To achieve a multi-disciplinary approach in tackling complex problems. For example, current multidisciplinary themes funded by UKRI Research Councils include: the digital economy, energy, global food security, tackling antimicrobial resistance, technology touching life, and urban living partnerships programmes.

- To pursue ambitious projects that may be beyond the resources of a single nation state. Past examples of such research include the human genome project and CERN. Longer standing examples include ITER (fusion research), the square kilometre array, the international space station and the (EU) human brain project.[803] More recent announcements include the global virome project to develop an atlas of all the major disease-causing viruses in the world, including details of their viral sequence, geographic range and the species they can infect,[804] and the human cell atlas to map all of the cell types in the human body in three dimensions.[805]

- To stimulate technological innovation. For example, investment in the human genome project is likely to have stimulated the increase in speed and decrease in costs of gene sequencing seen over the lifetime of the project.

- To achieve wider political or diplomatic aims and to establish closer international relationships (science diplomacy). Significant examples of science diplomacy include the international space station, CERN and the Pugwash conferences.

Implications and challenges

One of the key challenges facing the UK research sector is Brexit, as the UK is a net recipient of EU research funding and UK researchers are involved in much collaborative research with colleagues from other EU countries. Key challenges raised by Brexit for the UK research sector include:

- Replacing the funding UK universities receive from EU research programmes. For example, under FP7 (2007–2013) the UK received €8.8 billion of direct EU funding for research compared with an estimated contribution of €5.4 billion.[806] In 2015–2016, Horizon 2020 and other EU funding accounted for an estimated 11% of UK universities' research income.[807]

- Replacing researchers from other EU countries. Britain is a popular location for researchers from the EU. For example, from 2007 to 2016, 22% of European Research Council (ERC) grant holders chose to work in the UK, and the UK is the most popular choice of destination for researchers receiving Marie Skłodowska-Curie fellowships.[808] In total, in 2016 there were more than 31,600 EU nationals working in the UK academic sector.[809]

- Maintaining UK research collaboration with EU researchers. UK/EU research collaborations have grown since the 1980s. For example, the proportion of the UK's international research output that consisted of UK/EU collaboration rose from 43% in 1981 to 60% in 2012.[810]

- Maintaining UK participation in clinical trials. Currently the UK is a major location for clinical trials in Europe. For example, the UK is involved in around 25%–30% of the total number of trials in the EU, and around 40% of UK clinical trials also have sites in the EU.[811]

- Maintaining access to personal data for research purposes. Personal data are an essential resource for health and social research looking at the links between lifestyle and disease or education and life outcomes. Maintaining access to such data from EU member states will be a key challenge for UK-based researchers post-Brexit.[813]

Key unknowns

- Uncertainty over whether the UK will participate in the next round of EU research, Horizon Europe, which starts in 2021. The Wellcome Trust and Royal Society have both stressed the importance of continued UK involvement in Horizon Europe as an associate country.[812,813]

- Future of key EU-funded research facilities based in the UK post-Brexit. These include the ELIXIR (European Life-science Infrastructure for Biological Information) hub in the Wellcome Trust Genome Campus near Cambridge, the Instruct (Integrated Structural Biology) Centre at the University of Oxford, and the European Social Survey headquarters at City University, London.

- Future UK involvement in other EU-funded projects such as the Infrastructure for Systems Biology-Europe network (in which several UK facilities participate).

- UK future participation in the international nuclear fusion project ITER. The Government has announced that the UK will leave the European atomic regulator Euratom, but not clarified the UK's position on its future participation in ITER. The UK currently is a member of ITER through its current association with Euratom. It is also unclear whether the Joint European Torus facility near Oxford, which has been the test bed for the ITER project, will receive any further EU funding.[814]

- Uncertainty about the freedom of movement of academic researchers post-Brexit. The Wellcome Trust and the Royal Society have called for free movement of researchers at all levels between the EEA and the UK as being vital to maintain the UK's position as a leading centre for collaborative research.

- Uncertainty about the UK's future participation in EU clinical trials and future access to personal data from EU researchers for research purposes.