UNIVERSITY OF BIRMINGHAM

Forum for Global Challenges

Addressing the climate challenge

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Foreword

The threat posed by climate change to our world is well understood. We know that sharp reductions in carbon emissions are needed if we are to achieve the goal of the Paris Agreement and keep global warming below the CO_2 upper limit. This is a complex challenge for which there are no simple solutions.

The Paris Agreement was significant because it united countries in common cause and commitment to action. Only by working together can we face the threat that climate change poses to us all. Collective action only works if each of us are prepared to play our part.

Countries must reconsider their Nationally Determined Contributions (NDCs) and increase their ambition to reduce emissions. In February 2021, a UN report concluded the latest pledges would reduce emissions by less than 1% by 2030 compared to 2010. This falls well short of the 45% reduction the Intergovernmental Panel on Climate Change (IPCC) say is necessary to limit global warming to 1.5ºC. We must do better.

Ambitious pledges must be backed up by action. We owe it future generations to be responsible guardians of the natural world, upon which our health and prosperity depend. There is also a moral obligation upon us to help those around the world who lack the means to address climate change but will nonetheless suffer the consequences. If the United Kingdom's presidency of COP26 is to be considered a success, then we should demonstrate global leadership by getting our own house in order, while helping others to do the same.

Reaching net-zero will only be possible in partnership with the private sector. Business decarbonisation plans must therefore be supported by clear sector roadmaps and long-term policy support from government. Public investment in the green economy is vital to support jobs and leverage private sector funding.

Universities have a distinctive role as civic institutions engaged in both teaching and research. We exist to extend the boundaries of knowledge and to share what we have learned for the common good. Contributing to public debates is therefore very much part of our mission and we hope this publication will help to make expert insight more accessible.

But more than that, we want to inspire and give a platform to younger generations. We therefore launched a writing competition to give University of Birmingham students the opportunity to have their say on climate change. We are grateful to the judges – Dame Caroline Spelman, Professor Alice Roberts and Professor Hisham Mehanna – for selecting three worthy prize-winners and we are delighted to include these articles in this publication.

Climate change is, undeniably, a grave threat to our world. Yet if the history of human endeavour has taught us anything, it is that we can accomplish more than we believe possible if we come together, united in common purpose. Let us therefore use the opportunity presented by COP26 to reaffirm our commitment to action – and to one another.

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Introduction

Much has changed since the University of Birmingham was established by Royal Charter from Queen Victoria in 1900. We were the very first civic university in the United Kingdom, built up in a city that helped pioneer the industrial revolution that shaped our modern world. While our understanding of the environmental consequences of development has moved on since then, the commitment to our civic responsibilities remains a core component of our identity at the University of Birmingham.

Sustainability is rapidly becoming a core responsibility and will be an increasingly important aspect of all our lives. The University of Birmingham recently signed up to the Race to Zero campaign, which aims to build momentum around the shift to a decarbonised economy.

In 2022, we will convene the Forum for Global Challenges bringing people together to find solutions within the broad areas of climate change and inequalities. We are also proud to be an official partner of the Birmingham 2022 Commonwealth Games, which is aiming to be the most sustainable Commonwealth Games ever.

The challenges brought by climate change are closely linked to sustainability and are among the most pressing issues facing our world today. Addressing these effectively means that we must first understand the problems, before asking the difficult questions around how much we are willing to change our lives in response. Reaching net zero is achievable, but will involve many changes to how we live, including for resource and energy efficiency, technological shifts and societal choices, driven by well-designed policy.

This report has been written to make expert insight and evidence accessible to those who are interested in climate change. We invited people from across the University of Birmingham community – and beyond – to write about topics relevant to the upcoming COP26 climate change summit. The opinions and conclusions expressed in these articles belong to their respective authors but, nonetheless, a few common themes did emerge.

We need to grow our understanding of the drivers of climate change, recognising that there are many complex and often interconnected issues at work. This will help us design better policy responses and technological innovations to mitigate climate change and help us adapt to a warmer planet.

Global decision-makers must prioritise funding climate research and knowledge transfer activities. Long-term planning and the development of a circular economy is essential. In the short-term national governments could incentivise sustainable behaviours and speed up the adoption of cleaner technologies through taxation and subsidies.

Climate change is not just a problem for the scientists and policy makers. Each of us has a responsibility to think about how our day-to-day lives can be made more sustainable. The role of the arts and humanities are often overlooked, but they can help win over hearts and minds, and inspire people to action. Though factual debate is essential, we should complement this with a narrative that inspires hope.

Adaptation and resilience

01

Climate change, infectious diseases and pandemics

Infectious diseases have been the most important cause of death in human history. Only since the late 19th century has our understanding of the microbial causes of infectious diseases led to the broad implementation of public health interventions to safely dispose of sewage and provide clean drinking water. From the 1950s onwards, the development of antimicrobial drugs and vaccines have been powerful additions to our arsenal against infectious diseases.

Collectively, these interventions and therapies have led to a significant decrease in deaths caused by infections globally, particularly in high-income countries. However, in the 21st century infectious diseases remain an important cause of death in the poorest countries in which the majority of the world's population lives. Since late 2019, the dramatic events of the COVID-19 pandemic have highlighted that infectious diseases still have the capacity to destructively affect even the world's most advanced economies and cause widespread suffering and death.

In this article, I will consider how climate change is already contributing to the global spread of infectious diseases. In addition, I will discuss whether new pathogenic microbes with pandemic potential are more likely to emerge and spread on a warming planet. Finally, I will outline potential interventions to rapidly detect and mitigate the spread of new and existing microbial threats.

An introduction to infectious diseases

Infectious diseases are caused by microbes, which include viruses, bacteria, fungi and parasites. The most important shared characteristic of all infectious diseases is that these microbes can spread between humans, thus causing the spread of the illness throughout populations. Sometimes this spread between two individuals can be direct and is described by the term 'human-to-human' transmission. Several important viral diseases, like measles and COVID-19, and the bacterial infection tuberculosis are important examples of illnesses that spread directly from human to human through the inhalation of droplets and/or aerosols that carry the infectious agents.

Other infectious diseases need an animal intermediary (termed a vector) for transmission. Important vector-borne infectious diseases are malaria, which needs the Anopheles mosquito to transmit, and plague, which is caused by a bacterium that can be transmitted via fleas and their bites. The vast majority of infectious diseases are zoonotic, meaning that the infectious microbe has, at some point in its natural history, jumped from an animal host to humans. SARS-CoV-2, the virus that causes COVID-19, appears to be an example of a zoonotic virus as current evidence points towards it having been carried by bats before it made the host jump to humans in late 2019. Other pandemic viruses are also zoonotic. HIV, the virus that causes the disease AIDS, is thought to have crossed from chimpanzees to humans in the 1920s.

For influenza viruses, livestock and poultry are important hosts where new forms of the virus can emerge and subsequently spread to humans. In the vast majority of cases, the host jump of a virus to humans will not result in an infection that is characterised by sustained human-to-human transmission. However, the pandemics of the last century, including HIV, Zika, Ebola and COVID-19, have shown that novel viruses can still spread rapidly across human populations. The COVID-19 pandemic should thus not be seen as a unique 'Black Swan event', but rather as a warning to future generations that pandemics will always remain a threat to humanity.

Climate change changes the geographic range of vectors of infectious diseases [1]

Global warming is changing the geographic range of mosquitoes and other insects that act as vectors for infectious diseases. This is now broadly recognised as a major threat to global public health. As an example, mosquitoes of the genus Aedes, particularly Aedes aegypti (the yellow fewer mosquito) and Aedes albopictus (the Asian tiger mosquito) are important vectors for viral infectious diseases including yellow fever, West Nile fever, Zika and Chikungunya. Since the 1960s, global trade in products like tyres and potted plants, which provide habitats for the development of larvae of A. aegypti and A. albopictus, has led to the introduction of these mosquitoes into North America and Europe. Winter temperature is likely to be the most important factor in determining how far these mosquitoes can spread to higher latitudes. With milder winters becoming more common on a warming planet, it is thus likely that these mosquitoes will spread further northwards in Europe and North America in the 21st century. In a worst-case 'business-as-usual' scenario for climate change, nearly a billion individuals will be newly exposed to these Aedes mosquitoes and the viruses that they can transmit. Current scenarios do not foresee a spread to the United Kingdom, but the mosquitoes are likely to become endemic across popular southern European destinations for tourism, thus potentially leading to increasing numbers of travel-related infections across Europe.

Ecosystem upheaval will increase human-animal interactions, facilitating virus-host jumps [2]

An estimated 10,000 viruses that are currently circulating in wildlife are thought to be able to infect and spread among humans. These viruses are entirely unknown to science and humanity will probably only first know of them after they cross the species barrier to start causing disease in humans, similar to SARS-CoV-2 and HIV. On a warming planet, many of the ecosystems on our planet will undergo dramatic changes, which will lead to the movement of many animal species into new habitats. For example, the climatic changes in the 21st century are likely to contribute to increased droughts and larger, uncontrolled forest fires. These fires will not only directly affect the carbon balance on our planet, as tropical rainforests are among the most important carbon sinks on the planet, but will also lead to migration of animals from regions that are affected by fire. When animal populations move from their original habitats to new sites, there is an increased risk that they come into contact with humans, thereby increasing the risk of animal-to-human transmission of the viruses they carry. This is particularly relevant for bats, who are broadly recognised as an important reservoir for novel viruses. The capacity of bats to fly allows them to travel hundreds of kilometres within their lifetime, thus potentially contributing to the dissemination of novel viruses on continental scales after their original habitats have been disrupted by climate change.

Climate change and antibiotic resistant bacteria [3]

The previous sections have mostly focused on viral diseases. However, infections caused by bacteria remain an important cause of disease and death globally. Since the mid-20th century, bacterial infections have been treated with antibiotics. Worryingly, bacteria that have evolved resistance to these drugs have become increasingly widespread. Infections caused by these antibiotic-resistant bacteria are becoming increasingly difficult to treat due to a lack of development of novel antibiotics. Antibiotic resistance can be regarded as a 'slow pandemic' that takes decades to spread, but can result in 10 million deaths per year by the year 2050. It may make medical interventions that are currently considered routine very risky as we would no longer be able to rely on antibiotics to suppress and cure infections.

[1] For further reading on this topic see: https://journals.plos.org/plosntds/article?id=10.1371/journal.pntd.0007213; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3614918/ and https://www.nature.com/articles/s41564-019-0376-y

[2] For further reading on this topic see: https://www.bmj.com/content/371/bmj.m3389; https://www.biorxiv.org content/10.1101/2020.01.24.918755v3.full and https://www.who.int/globalchange/publications/climatechangechap6.pdf

Whereas antibiotic usage in human and veterinary medicine is broadly recognised as the leading driver for the emergence and spread of antibiotic resistance, recent research has shown that increasing temperatures in Europe and North America are associated with higher levels of drug-resistant bacteria. The mechanisms that are driving increased levels of antibiotic-resistant bacteria at higher ambient cultures are currently unknown. It is possible that the process of horizontal gene transfer, the exchange of DNA containing antibiotic resistance determinants between bacteria, is increased at higher temperatures. Global warming may thus directly contribute to the rapid spread of antibiotic-resistant bacteria across the planet.

A global response to infectious diseases in the age of climate change

To mitigate the impact of climate change on the spread of infectious diseases, we can build on the experience of the COVID-19 pandemic, which has made it abundantly clear humanity always needs to be prepared to go to battle with its microbial enemies. Rapid deployment of non-pharmaceutical interventions and the development of novel drugs and vaccines will remain cornerstones for an effective response to infectious diseases. In addition, global networks for surveillance and monitoring of infectious diseases, particularly in settings where humans and animals interact, e.g. in the vicinity of bat colonies, will need to be expanded to rapidly flag and identify new outbreaks of infections. Similar surveillance efforts are needed to map the spread of insect vectors of infectious diseases. These should be combined with public information campaigns to promote interventions to minimise insect bites and raise awareness when new infectious diseases are introduced through insects. Climate change is predicted to first affect the poorest nations on the planet. These countries generally already have high rates of infectious diseases and often harbour ecosystems that can be conducive to animal-to-human transmission events of pathogens. On a warming planet, a truly global effort is thus urgently needed to stem the emergence and spread of new and existing infectious diseases.

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[1] For further reading on this topic see: https://amr-review.org/sites/default/files/160525_Final%20paper_with%20cover.pdf; https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6201249/ and https://www.eurosurveillance.org/content/10.2807/1560-7917.ES.2020.25.45.1900414

The role of healthcare in carbon reduction

The impact of Covid-19 on the UK National Health Service (NHS) was dramatic and instantaneous, and while some changes were immediate and obvious, others will arguably take months and years to become evident. One area where short term responses could have longer term implications is around the environmental impact, or sustainability, of healthcare delivery. This article will explore the role that healthcare can play in contributing to carbon reduction and how the sector can move towards improved sustainability. We will consider how the pandemic accelerated imperatives in health service delivery towards carbon reduction, wittingly or otherwise, including the use of innovations or initiatives that were previously available but sometimes under-utilised (telehealth, e-consultations, the greater use of patient self-monitoring for instance). These adaptations have long existed or been possible, but the 'forced innovation' and wider adoption provides a timely impetus towards sustainability, with benefits arguably also relating to improved patient care and experience.

Healthcare and environmental sustainability

The relationship between health, healthcare delivery and environmental impact is cyclical and symbiotic – 'environment', in its broadest sense, is a key determinant of health, and the resource-intensive delivery of healthcare in developed economies has a clear impact on the environment. To ensure a deeper understanding of how these factors interact, and how carbon reduction in healthcare is not only desirable but a plausible policy choice, it is worth exploring this relationship in more detail.

The links between climate change – the use of finite resources, the impact on the health of communities and populations, and the delivery of modern healthcare – has been the subject of study for many years. Even a brief review highlights some startling issues. As far back as 2011, carbon emissions from the healthcare sector in the United States accounted for 10% of total US emissions; in 2012, the King's Fund pointed out that "carbon dioxide emissions attributable to the NHS in England alone are greater than the total emissions from all passenger aircraft departing from Heathrow Airport"; and more recently, a paper in the Lancet explored the tension that "health-care services are necessary for sustaining and improving human wellbeing, yet they have an environmental footprint that contributes to environment-related threats to human health". The NHS made a bold commitment to 'net zero' in October 2020, acknowledging as it did so that "we therefore make no apologies for pushing for progress in this area while still continuing to confront coronavirus". Meanwhile, for practitioners, the Centre for Sustainable Healthcare contains a myriad of material "… to engage healthcare professionals, patients and the wider community in understanding the connections between health and environment and reducing healthcare's resource footprint". This includes educational resources, analytical debate and practical toolkits. In some ways, therefore, the field around the environmental impact of healthcare commissioning and delivery, and thinking around sustainability, has never been richer, and the resources for policy-makers are wider than ever. The emergence of the coronavirus pandemic, however, pushed healthcare systems (such as the NHS) into a turbo-charged 'adapt to survive' crisis footing which, as we will turn to next, had significant implications for the use of scarce resources.

Covid-19 – the impetus for change

Much is written about how humankind will respond to climate change challenges, whether this will be through a carefully planned policy response with prospective adaptation, or reactive responses to various climate emergencies. Almost certainly, these two drivers will intertwine, each reinforcing the other in a feedback loop along with the occasional jolt from an external 'shock'. The Covid-19 pandemic was just such an external shock, and it can be instructive to explore the response of health services through the lens of environmental impact – was this congruent with, or did it confound, the paradigm of the dual prospective and reactive response?

At an operational level, the impacts of the pandemic on health service delivery were immediate and obvious. Face to face consultations across all specialties were drastically reduced, and given that 90% of NHS interactions take place in primary care, this impact would have been highly noticeable to all users. What followed, not only in primary care but across all parts of the NHS, was remarkable.

Adaptation and sustainability in health

The NHS Long Term Plan, published in January 2019 signalled a move to 'digital first' primary care well before the advent of Covid-19. The importance of investing in digital technology has been signalled for many years (e.g. the Wanless Report and the Topol Review), although progress has been inconsistent. What happened, as a result of the pandemic, laid bare the drivers and determinants of health, with digital poverty and inequality as real as any of the more traditional drivers. It is indisputable that the pandemic has significantly accelerated digital health beyond all expectations with more than 99% of GP practices now activating remote platforms to provide some form of e-consultation, but this could just as easily reinforce other inequalities, such as digital poverty. Whilst the impact of remote GP consultations carbon reduction has not been quantified, it is intuitively indicated, most obviously via, for example, transportation emissions. However this needs to be considered (especially from a policy perspective) on a broader landscape of what is a 'good life' and a 'good society'.

In addition to e-consultations there has been a massive roll out of remote self-monitoring for patients with pre-existing conditions and for those testing positive for Covid-19. Known as 'digital health' these innovations are set to have long-lasting implications for sustainability. For those with pre-existing conditions, the challenge has been how to replicate the support which multi-disciplinary acute and/ or community health teams were providing pre-pandemic. The development of virtual wards has been scaled up, enabling patients with long term conditions to be cared for at home and reducing the need for outpatient attendances and other follow up, with clear implications in reduced travel to clinical sites. In some cases, such as remote monitoring pilots, these changes have built on work already underway with the pandemic giving it extra impetus. For example, the Joined-up Care Approach across Yorkshire includes a project originally focussed on primary and secondary care extended to children and young people with life-limiting illness who are looked after by the paediatric palliative care team or those with a chronic condition like Cystic Fibrosis under the care of the paediatric respiratory team. The pandemic shifted the focus to enabling remote home monitoring of these children and young people to reduce their need to visit hospital. In another project (in the North East of England), a remote ECG pathway to support patients and staff during the pandemic met with overwhelmingly positive evaluation from patients and staff and offered clear benefits in reducing the need to travel to hospital. The NHS Trust involved has now taken the decision to use these permanently, procuring and distributing over 100 devices across 100 community teams.

Learning from and promoting best practice and rolling it out at scale has been a feature of the NHS response to the pandemic, with the provision of home monitoring of oxygen saturation levels being a good example (other responses can be seen here). Home oximetry (using small, cheap oximeter devices enabling self or carer monitoring) has been one digital enabler of the development and expansion of Covid Virtual wards. These were set up to enable hospital patients to be discharged home earlier with ongoing monitoring in place, with obvious benefits to patients and reduced resource consumption. The unprecedented national roll out of oximeters to assist those who test positive for Covid-19 and/or are otherwise at risk of silent hypoxia, helping them determine when to contact NHS111 or when to go to A&E, has seen 300,000 home oximeters supplied to patients across England by January 2021, and similar partnerships are springing up across the country and bringing undoubted patient benefit.

These examples illustrate how necessity can drive innovation, but that this can play into patient empowerment and carbon reduction simultaneously. The concept posited earlier in this piece, of the intertwining feedback loops around innovation and change, appears sound, with an interdependence evident. Many virtual wards have been built on the earlier principles of rapid response teams which already existed in many community trusts. The story of adaptation is not a foregone conclusion of positive outcomes, however. For instance, elsewhere digital pilots have been seen as less successful, such as the provision of iPads into care homes which have focussed on the provision of digital kit and neglected the equally important aspects of clarity of the pathway, especially escalation, and the enablement, education and support of other patients, carers and other parts in the care system. The use of technology for the sake of it can result in a cul-de-sac. The longer-term issue as we move into service resumption and recovery will be partly driven by ongoing financial viability in terms of the deployment and consumption of resources, and significantly driven by the ability to demonstrate transparent gains in terms of benefits to service users, their carers and families.

Policy implications

Any policy response to the environmental emergency facing the planet must be about leadership. A challenge for leaders is often framed as creating the conditions for change – articulating a vision, securing resources, understanding and nurturing motivation. At times such as these, in response to a massive external shock, that leadership challenge arguably morphs into riding the wave of change, securing the benefits and maintaining the impetus. Now, perhaps more than at any other time, the need for vision and the ability to develop strategic partnerships is more critical than ever. So, the role of the public sector leader also comes to the forefront; connecting and harnessing public good with real, operational change. Quite simply, healthcare consumes enormous amounts of resource, and so the potential impact of change is equally significant.

A policy response is as much a matter of an understanding – knowledge and attitude – as a set of 'prescribed solutions'. Certainly, interested policy-makers can already access a range of resources that would surely find congruence in a range of contexts – in this area as much as any other, one size does not fit all, but that is not a reason for inaction. Sustainable healthcare is also a moral imperative, with clear congruence with other ethical dimensions of healthcare provision; ensuring that routes of access are as wide as possible, the efficient and equitable distribution and use of scare resources, patients and service users being completely clear about choices (and the limits of choice) and the implications of their choices. As trusted sources of health information, health workers can have a pivotal role in educating and informing colleagues and service users about the health effects of climate change and the need for an efficient use of resources from an environmental, not purely monetary, perspective.

So, viewed through the lens of sustainable healthcare, the response to the pandemic was a classic combination of a reactive response, but prompting long-needed innovation and change. Necessity forced innovation, but innovation creates momentum, which leaders can both consolidate to 'bank the gain' but also use a platform for sustained policy change. It is often the case in healthcare that the evidence base is constructed iteratively, and this can apply to wider carbon reduction and sustainability polices too. Healthcare adapted to survive the pandemic, and sustainable healthcare is arguably a more realistic and achievable policy choice as a result. In any event, this might be less a choice than a necessity in itself; in all likelihood, it will not be the last time that health emergency and climate emergency meet.

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Improving the climate resilience of infrastructure networks

The functioning of society is dependent on reliable infrastructure. Any loss of essential services such as energy, water and mobility results in significant health, wellbeing and economic impacts. The day-to-day performance of our infrastructure, however, is impacted by the weather. Extreme weather events such as heatwaves and flooding highlight existing vulnerabilities in our infrastructure systems. These extreme events provide a window into what the future may hold in the face of climate change.

The 2008 UK Climate Change Act was a world-leading piece of legislation. It brought a step-change in the way the UK tackled climate change. The act resulted in the independent Climate Change Committee and also mandated that a UK-wide Climate Change Risk Assessment (CCRA) be completed every five years. Taking a sector-by-sector approach, the CCRA provides a regular stock-take to quantify the risks and opportunities associated with climate change, enabling the prioritisation of actions based upon urgency. Infrastructure is a key sector targeted by the CCRA.

The assessment of climate change impacts is crucial for long-term governmental planning. This is especially true in the infrastructure sector where adaptation planning is required on existing and, in many cases, ageing assets built to withstand a different climate to that experienced today (we still utilise some infrastructure dating from the Victorian era). It also means that any investment in new assets needs to consider a potential lifespan in excess of 50-100 years. Such 'lock-in' underpins the need to build climate resilience into all new infrastructure projects to ensure the maximum return on investments.

Where are we now?

Since the 2008 Climate Change Act, the UK has now completed two CCRAs and is into its third cycle (the third CCRA is slated to be brought before parliament in January 2022). The CCRA ultimately feeds into the latest iteration of the National Adaptation Programme (NAP) which sets out where the government will target adaptation over the next five years. It also outlines the latest process for Adaptation Reporting Power (ARP) where the Secretary of State has the power to direct reporting bodies (i.e. infrastructure owners and operators) to detail their latest plans to adapt to climate change. ARP was a mandatory process for the first two iterations but has since changed to an optional return. Underpinned by the United Nations Framework Convention on Climate Change National Adaptation Plans process, other countries throughout the world have adopted a similar approach. The majority of European countries have now completed a CCRA whereas the US has completed four National Climate Assessments. In all cases, there is clear evidence of economic flows into climate adaptation.

Despite this progress, adaptation continues to be too patchy and slow to make a significant difference on the ground. Each year brings new headlines of record-breaking weather impacting upon our infrastructure. Large scale flood events that damage property and isolate communities have almost become expected each winter. In contrast, record breaking temperatures wreak havoc on our rail networks during the summer. However, a challenge remains to directly attribute these individual events to climate change. Many extreme events remain within the boundaries of what is considered 'normal' for our weather – it is the frequency in which the events are happening that is increasingly not normal. The reality is that large quantities of infrastructure are not weather resilient, let alone climate resilient. Indeed, there is still plenty that needs to be done to understand the impacts of the current weather on infrastructure networks.

One of the biggest challenges that the infrastructure sector faces is the interconnected nature of its assets. For example, our mobility networks are becoming increasingly electrified meaning that a power outage will not only impact the electricity grid but also transport. Likewise, whereas the pandemic has brought into sharp focus our dependence on Information and Communications Technology (ICT), infrastructure too has become ever more reliant on the reliability of ICT networks (e.g. smart grids for energy). The potential for such 'cascade failures' across infrastructure networks means that the current responsibilities and adaptation decisions made by individual infrastructure owners and operators extend beyond their own assets. It is no longer just about getting their own house in order – dedicated data needs to be collected, shared and analysed for the greater good.

The other side of the climate change adaptation coin is mitigation. This, if anything, is more crucial than adaptation as we need to limit the scale of climate change (keeping global temperature rises around 1.5°C was the aim of the Paris Agreement). Prevention is better than cure after all! Announced in December 2020, the UK is aiming to reduce its emissions to net zero by 2050. This is ambitious, but in 2018, emissions were already 44% below 1990 levels – this is thanks in a large part to reductions in the energy sector. The drive to net zero has major implications for the infrastructure sector, even increasing exposure to the impacts of climate change in some cases. For example, a greater dependence on renewable energy may mean more offshore wind exposed to storm damage. A reliance on clean electricity for mobility will further compound risks from cascade failures.

Where are we heading?

The direction of travel is, unfortunately, clear. The UK is on its way to more extreme weather: warmer, drier, summers, and milder, wetter, winters. Not to mention the small matter of sea level rise which, left unchecked, will overwhelm some of our critical infrastructure on the coast. Taken together, all will have a significant impact on infrastructure with implications for mobility, energy generation and water resources – ultimately compromising the safe functioning of society.

It is acknowledged that the infrastructure sector is playing its part. Many of the key infrastructure owners and operators now have clear adaptation plans (e.g. Network Rail's Weather Resilience and Climate Change Adaptation plans) and investments are being made. However, there is a clear and pressing need to move away from any remaining 'siloed' thinking which may result in an increased risk of cascading failure across the infrastructure system. The infrastructure sector is just one system among many and failure can cascade even further beyond. This can only be resolved by high level oversight and policy and knowledge exchange between infrastructure organisations to develop a shared understanding of cross-sector risks. Within the UK, the Infrastructure Operators Adaptation Forum (IOAF) brings together senior transport professionals, local and national government, independent bodies such as the Climate Change Committee and Environment Agency and academics to share and create best practice in weather resilience and climate adaptation.

One of the biggest challenges for investments in adaptation are defined time periods. The CCRA and NAP operate over a five-year timescale (i.e. the length of a typical governmental term of office). Likewise, infrastructure owners and operators work to defined control periods. All contribute to short-term thinking in adaptation planning which is not conducive to truly tackling the impacts of climate change that will be felt over decades. The consequence is incremental adaptation when what is really required is transformative adaptation – the two do not need to be considered as different. There is scope to develop adaptation pathways which can evolve with the risk. Although more expensive in the long term, these reduce the scale of the investment in the short term. However, this approach is constrained by working to short time horizons and is no longer underpinned by mandatory reporting via ARP.

Conclusions

The UK's approach to climate resilience and adaptation has been world-leading and has served as the basis for similar approaches internationally. The statutory framework of rolling national risk assessments and adaptation programmes has helped to embed the adaptation process in government and non-government bodies and is starting to feed through into actions on the ground. However, the current siloed nature of adaptation, along with the political and institutional barriers to long-term planning mean that the truly radical and transformative changes that could build a climate resilient nation are arguably not being sufficiently nurtured. Therefore, based on these conclusions, the following recommendations can be made:

1. Longer term thinking is essential. Building cross-party consensus for both climate change mitigation and adaptation is crucial to overcome incremental adaptation.

2. ARP needs to once again be a mandatory process aligned to the CCRA and NAP. Without this comprehensive input, it is almost impossible to assess progress towards targets.

3. Encourage further high level oversight and investment to improve the evidence base and mitigate against interacting / cross sector risks.

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The implications of net zero ambitions for infrastructure resilience to climate change

On Earth Day 2021, the 22nd April, USA President Joe Biden hosted a virtual summit with 40 world leaders, announcing new pledges to decrease greenhouse gas emissions. These reductions are to meet the objectives of the 2015 Paris Agreement; an international agreement to reduce global warming to well below 2 compared to pre-industrial levels. 2 is considered the critical tipping point in global temperatures after which changes in the climate system may become irreversible. In some respects, the USA is catching up with the rest of the world – currently, 124 nations have pledged carbon neutrality.

The Climate Change Act 2008 mandates UK reductions in greenhouse gas emissions; the first country in the world to do so. The revision of this Act in 2019 changed the target from an 80% reduction to 100% reduction in net greenhouse gas emissions, from a 1990 baseline by 2050. In other words, by 2050, the UK should no longer be a net emitter of greenhouse gases, achieving "Net Zero". There are also interim targets, 68% reduction by 2030 and 78% by 2035. However, in order to transition to Net Zero, the energy, water, transport and Information Communications Technology (ICT) sectors will need to modify or rebuild their infrastructure, or change the way they operate. The Net

Zero goal now means that the transitions need to be more ambitious, and possibly accelerated. The difference in the trajectories are shown below in Figure 1.

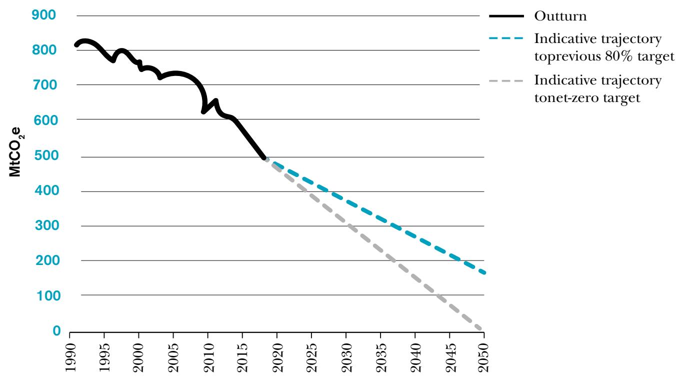

Figure 1. The difference in greenhouse gas emission trajectories over time based on the original Climate Change Act target (red) compared to the new Net Zero target (green). The black line is historic data. **Source:** Committee on Climate Change's 2019 Progress report to Parliament.

Despite the need to reduce emissions, there is no denying that changes in the climate are already taking place: 2020 was one of the warmest years on record, and 2011-2020 was the warmest decade on record. There is evidence that this warming has already led to observed changes in extreme weather, such as heat waves, drought and heavy rainfall events. Consequently, extreme weather affects infrastructure directly, for example:

- Flooded substations affecting electricity provision,
- Drought reducing water supply,
- Railway tracks buckle in a heat wave affecting service levels.

There are also indirect consequences of extreme weather on infrastructure, such as:

- Increased energy consumption during a heat wave to operate more air conditioning units,
- Periods of drought increasing demand in water supplies,
- Loss of power to an electrified train service if a severe flood damages its respective power supply elsewhere.

Therefore, any changes in the energy, water, transport and ICT sectors to reduce greenhouse gas emissions may need to take into account the expected impacts of climate change on their changing infrastructure so they can continue to operate. This complicated area is emerging in infrastructure risk assessments, as it will become imperative that infrastructure decisions on mitigating and adapting to climate change do not negatively affect each other. Here, we outline how Net Zero changes may affect infrastructure's resilience, broken down by each sector.

Energy

The energy sector has a very large role to play in reaching UK's the Net Zero goal. This includes the growth of renewable energy infrastructure such as solar, wind, hydro and tidal alongside biomass, nuclear, hydrogen and carbon capture and storage (CCS) technologies. Increasing levels of intermittent, weather dependent generation presents challenges in managing the power network as outputs vary daily and seasonally across the UK. This could be particularly challenging when there are sharp peaks in diurnal demand that coincide with low renewable outputs e.g. cloudy, still days.

On this basis, an array of supporting measures are included, including new nuclear and biomass with CCS, energy storage and various demand response solutions. Hydrogen generation is also emerging as both a medium of energy storage via electrolysers and a fuel for more energy intensive users such as HGVs and trains. Some estimates have a new hydrogen economy supplying comparable levels to the current gas-fired power station infrastructure. In addition, nuclear plants are likely to remain in place as a low carbon source of energy, although the level of deployment is uncertain as the growth of renewables expects to provide lower future costs. To reduce the life cycle greenhouse gas emissions to zero from these supporting measures, CCS is required. It is a process of capturing emissions at the source, transported via pipelines or shipping and stored back deep into the ground. It prevents carbon dioxide, the primary greenhouse gas, from entering the atmosphere in the first place.

All of these changes in energy infrastructure: renewables, hydrogen, new nuclear and CCS are vulnerable to climate impacts, with their exposure dependent on their location. For renewables, the implications are variable. On one hand, wind speeds up to a cut-off point of 25m/s can increase output; and heavy rain can increase hydropower output. However, on the other hand, a period of drought could lead to crop damage and loss of biomass feedstock. A balance of technologies and their geographic spread are necessary to manage fluctuations in outputs especially as we may see increases in extreme weather events. This is why investing in demand side response and storage technologies are options to reduce the impacts of variable outputs from renewables. As for hydrogen and CCS, both are dependent on water availability. Infrastructure rollout is in early stages and sites have not yet been selected so the impacts are less clear. CCS infrastructure requires more water compared to traditional thermal generation, and hydrogen generation also requires water so there is as assumed risk to these processes during periods where water supply is low, or during a drought, or in water stressed areas, such as the southeast of England. As for hydrogen, if supply in the future uses the existing pipeline network used for gas, there are potentially similar risks to current levels of knowledge.

Water

The water sector is responsible for providing water supplies to society but also for treating wastewater, which requires energy and produces greenhouse gas emissions. As climate projections for the UK anticipate warmer, wetter winters and hotter, drier summers, managing water resources year-round is necessary to meet Net Zero targets.

As water supply and treatment infrastructure is located where waterways are, they are unlikely to change. However, a lot of the opportunity to reduce greenhouse gas emissions is in electrifying processes instead of using fossil fuels: either through the national grid or additional decentralised infrastructure on-site. Compulsory metering of water for customers is a possible way of reducing water consumption, ultimately reducing the energy required at water treatment facilities. In addition, a recommendation to manage nationwide water supply is through creating a national water transfer network.

Sustainable drainage systems (SuDS) infrastructure has grown across the UK as a way of managing storm water locally. They mimic natural drainage and passively treat flood and pollution risks due to urban runoff. Examples include designing new swales, wetlands and reed beds, such as that in Figure 2. SuDS can reduce the amount of water entering combined sewers, also reducing the energy demand at water treatment facilities. It requires collaborative work with the water sector and bodies such as Local Authorities and the Environment Agency. This intervention provides additional climate adaptation benefits with studies indicating green (vegetation) and blue (water) infrastructure can reduce urban temperatures.

Figure 2. Award-winning SuDS designed in the recently built residential area of St. Andrew's Park in Uxbridge, the London Borough of Hillingdon. **Source:** Greater London Authority, Susdrain.

The climate change impact of the changes required for the water sector are not yet clear. An assumed risk may be related to the increased dependency on a changed energy supply for wastewater treatment. For example, if the energy sector cannot produce enough electricity, it affects the water sector's ability to treat wastewater. A similar risk would also apply if the water sector supplier's on-site renewable energy supply was insufficient, or without appropriate energy storage. For coastal infrastructure, this would also be a challenge regarding sea level rise. There may be increased stresses on treatment and pumping of seawater, as well as the threat of coastal erosion to the physical infrastructure. In addition, national water transfer infrastructure could increase risks such as higher energy demands and hastening the spread of invasive and/or non-native species through water. As for SuDS, future risk to them is also not clear.

Transport

Road, rail and aviation infrastructure requires significant changes in order to meet Net Zero targets. Vehicle use is a major contributor to greenhouse gas emissions and a switch to electric vehicles and a phase-out of petrol and diesel is critical. Electrification of rail infrastructure and hydrogen train trials are underway, as well as research into lower carbon intensive fuels for planes, such as using biomass. Changing modes of transport also helps reduce greenhouse gas emissions e.g., private car use replaced with public transport (bus and/or rail); shorter car journeys replaced with active travel modes (walking and cycling); air travel replaced with high-speed rail.

The transport sector as a whole is very complex as there are many stakeholders and owners of the infrastructure across the UK. Therefore, changes to its infrastructure will require collaborative work between sectors, transport operators and government bodies at multiple levels. For example, the infrastructure required to support a growing fleet of electric vehicles (i.e. charging points) affects a range of stakeholders, through multiple national government schemes:

- Homecharge and Workplace Charging scheme (for residents and businesses)
- On-street Residential Chargepoint scheme (for Local Authorities)

The Automated and Electric Vehicles Act 2018 also makes provisions about electric vehicles, including charging infrastructure, and gives the government powers to ensure motorway services provide them.

The transition to Net Zero for the transport sector will have an increased dependency on electricity, particularly for road and rail due to electrification. Therefore, there is a greater risk if things go wrong in electricity supply, especially due to the transitions in the sector. Some other risks across the transport sector are specific to the mode, *such as:*

- Rail: Overhead lines (increased due to electrification) are more susceptible to sag during high temperatures.
- Active travel: health related risks from heat exposure, or injury from surface run-off due to extreme rainfall (although from a public health perspective a modal shift to active travel will have many benefits).

Information Communications Technology

Our dependency on ICT has increased rapidly in recent years. This infrastructure was first made of copper cables, but the transition to Net Zero requires a transition to fibre optic cables. This is because not only do they provide better internet speeds, but also use less energy. The National Infrastructure Commission recommend that full nationwide coverage of fibre broadband is delivered by 2033, allowing for a copper infrastructure switch-off by 2025. This improved coverage could also support the growing demand for remote or home-based work, therefore reducing commuting trips and contributing further to Net Zero goals. However, as other sectors increase their use of smart technologies, reliance upon ICT increases with the potential for cascading failures cause by ICT outages.

The ICT representative report to the Government's Second Adaptation Reporting Power outlines some of the climate adaptation related risks to this transition. For instance, copper and fibre have different vulnerabilities. Due to the electronic circuitry, a fibre cabinet is more likely to suffer catastrophic damage if flooded compared to a copper cabinet. In addition, ICT infrastructure changes more rapidly than any other infrastructure sector, which may present more unknown risks and vulnerabilities in future.

Conclusion

The infrastructure sectors in the UK are at different stages of their pathway to Net Zero, with differing risk profiles to climate change. In particular, there are growing interdependencies of water, transport and ICT on the energy sector. There are indications of increased electricity use for the Net Zero transition, which exposes other networks to the impacts on the energy sector through cascading failures. Similarly, there is an increasing reliance on ICT for the operation of the power network and other sectors using 'smart' grids and other 'smart' technologies. Therefore, it is extremely important to address this between the sectors in order to collaborate on solutions that protect against cascading failures. As Net Zero transition is necessary, adapting this changing infrastructure to the effects of climate change is equally as necessary.

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The case for an International Climate Year

Climate Change is the overarching challenge for generations to come, but currently the world's efforts are lacking impetus, steering and cohesion. Looking to the past for inspiration, our scientific ancestors brought together institutions from around the globe to address specific problems and achieve the cohesion we now need on numerous occasions.

One such example is the 1957/1958 International Geophysical Year. Together, they made significant breakthroughs in the fields of geology, oceanography and meteorology through a massive collaborative effort to improve observation networks and share data. Today, it is not a unified observation network we lack, but rather a unified sense of direction. In this spirit, we propose to proclaim and conduct an International Climate Year to foster international collaboration, further our understanding of the climate system, and perhaps most importantly, reframe climate change not as an inevitable disaster we cannot avoid, but rather as a challenge that humanity has accepted.

In 1992, the World's Scientists delivered a warning to humanity. If our behaviour did not change, we would put at risk our ability to sustain life in the manner that we know. Two years earlier, the Intergovernmental Panel on Climate Change had delivered their first report, outlining the potential impacts of climate change on humanity and the natural world, and recommending a comprehensive global response. We have not merely procrastinated on addressing this problem, but far worsened it, as the Union of Concerned Scientists noted in the 25th anniversary of the first warning to humanity. With the exception of ozone depletion which was addressed through the banning of ozone detrimental substances, every environmental problem identified by the first warning has since been exacerbated. Since 1990, CO_2 emissions have continued to increase and in response the global temperature has warmed by over half a degree Celsius. The impact of this warming has already been felt globally through increased frequency of heatwaves, decreased crop yields, ecosystem loss amongst many other devastating consequences. The 1992 warning to humanity has gone unheeded, leaving our home under serious threat.

How did that last paragraph make you feel? Fearful for the future maybe? Worried about what we're leaving for the next generation? Angry at the lack of Government co-ordination? Or guilty because you aren't doing enough? Maybe you just have a sense of déjà vu, having read and heard it all before. I know this. We all know this. Or maybe it just left you feeling helpless. How many more times can we say "we must act now!" and then not act? Anyway, what can I do? Maybe it's already too late. Maybe there's no point doing anything. Maybe it won't be that bad.

It wouldn't be surprising if you had any or all of those thoughts, because we know that doom-laden messaging often results in a lack of action or behavioural change as people switch off to avoid the associated negative feelings. This is particularly true for an issue like climate change, where both the problem itself and the solution feel far away and difficult to conceive. In fact, it is hard to imagine a more difficult policy issue than climate change; the impacts occur slowly over many years and it can only be resolved through global co-ordination. Doing your part will not isolate you from the consequences. Perhaps this explains why the environment lags behind issues such as immigration, the economy and regional issues (e.g., *Brexit*) in the UK's public concerns. The urgency of the warnings has not inspired a similar urgency in the general public, at least compared to the issues which feel more local and immediate.

Michael Angus, Gregor C. Leckebusch, Kelvin Ng, Lisa Degenhardt and Gabi Hegerl

The case for an International Climate Year

As an alternative to doom-laden messaging, evoking hope is most associated with supportive attitudes and policy advocacy. It is not enough to simply list all the problems we face with climate change, scare people, and then tell them they must act now. Continuing to do so will lead only to avoidance, feelings of anger and helplessness. What we need is a focussed solution that an individual can act upon, with leadership, direction and a message of success. What we need is an International Climate Year.

An International Climate Year would evoke hope rather than despair for a number of reasons. First, it provides a sense of immediacy by removing the issue of "some time in the future" that is predominant in the current climate change discussion. It is not a target of what we can do by 2035 or 2050, but rather "what can we achieve now?". Second, it reframes climate change as a challenge humanity is seeking to resolve, rather than as an impending crisis. Finally, by evoking the achievements of the past, it offers a tangible example of what can be achieved through a spirit of global co-operation in science. In making the case for the International Climate Year, we must first make the case for the importance of the International Geophysical Year, the historical collaboration of scientists which began the Space Race and changed the way we see the Earth forever.

Running from July 1st 1957 to December 31st 1958, the International Geophysical Year included scientists and observations from every continent and 67 countries. Conceived by leading geophysicists Sydney Chapman and Lloyd Berkner, it was, at the time, the largest set of coordinated experiments and field expeditions ever undertaken. Even the United States and the Soviet Union shared data, with weather and seismology stations all reporting to central data bodies in a successful effort to create global data networks for the first time.

Although tensions remained between scientists of the two superpowers, particularly over data from the first artificial satellite launches (the Soviet Sputnik 1 in October 1957, and the American Explorer 1 in January 1958), the overall mood of global scientific collaboration held. The Antarctic Treaty, signed to protect resources and to promote research in the region, was a substantial achievement of the International Geophysical Year and still holds to this day. Some examples from the many scientific advancements include:

- The discovery of Mid-ocean ridges through echo sounding from American and Soviet Research vessels, providing supporting evidence for the theory of continental drift for the first time.
- The discovery of the Van Allen belts, zones of high solar radiation surrounding the Earth. A hazard to humans passing through them, this was an essential piece of information for future space missions.
- The first record of CO_2 levels in the atmosphere at the Mauna Loa Observatory in Hawaii, which still records to this day as a key component of the climate observing system.

However, the International Geophysical Year was important not only because of the scientific achievements. It proved scientists could cross political boundaries and work together for the shared benefit of all. This is all the more impressive for having occurred during the Cold War. The weapons of war were turned instead to science: rockets were used to observe stratospheric temperatures by recording the fluctuations in sound made when grenades, fired from the rocket mid-flight, exploded at high altitudes. Nuclear weapons were also used to test the seismology network, both for improvements in earthquake measurements and so that seismologists could monitor nuclear tests around the world in future. Even Walter Sullivan's first-hand account documenting the achievements was entitled "Assault on the Unknown". The International Geophysical Year is pockmarked with the violence and problems of its time, yet brightened by scientists' attempt to solve them.

The challenges we face now are not the same as those early geoscientists, of course. However, to combat climate change we require the same spirit of global co-ordination and unity of purpose. Evoking the spirit of that time is a fine start, but what activities would an International Climate Year actually involve? We discuss here three broad categories within the scope of the hope themed message: Public encouragement, Public engagement, and Public advocacy.

To encourage the public that climate change is being addressed, we would promote a wide range of international projects on the theme of tackling climate change from the world's scientists. This would include researching new energy technologies, applying mitigation and adaption proposals, geoengineering projects and further research into key climate uncertainties. By bringing together these currently ongoing research activities, we present the public with a united message whilst furthering research in these key areas.

To engage the public with climate change research, we propose a range of citizen science projects dedicated to bringing the public together to participate in science directly. This was also an essential element of the International Geophysical Year, with initial tracking of artificial satellites performed by volunteer astronomers engaging in Operation Moonwatch. Projects like Zooniverse offer that opportunity today, furthering research goals through volunteer contributions that allows everyone to contribute to tackling climate change. Similar messaging has been employed recently during the COVID pandemic, where the UK Government encouraged us to #DoYourBit to protect the NHS.

To promote public advocacy for climate change, we would encourage the International Climate Year as a year to change behaviour, both at a personal and government scale. Research projects that study gaps in the current understanding and discussion would be encouraged, with a focus on more transparency in the process of policy mechanisms such as the IPCC and UN Climate Change Conference. The public must feel

engaged in the policy discussion, so that the solution does not feel like something foisted onto us undemocratically. Education is also vital, with science communication activities that go beyond the "knowledge deficit model", educating climate scientists and the public alike so that we can better communicate with one another.

None of these proposed activities involve radical change, and a large number of them are happening already. An International Climate Year would simply provide a focal point for these activities, while simultaneously providing an example from history of scientists coming together to address a major issue of their time.

The success of the International Climate Year would be measured by its legacy. The legacy of the International Geophysical Year is vast and undeniable; a new way of perceiving the Earth through global observations, better understanding of the physical processes that shaped the land beneath our feet and global policies which are still in place today. If we are to strive to match that level of achievement, the International Climate Year will require real commitment from scientific institutes and governments, and be international in more than just its name. Yet, we must think on this scale if we are to make real progress on climate change.

While climate change may be an invisible problem, the impact on our environment is not. The global nature of the issue provides a unique opportunity for engagement at local level everywhere, with direct access to climate change projects, adaption and mitigation strategies making climate science directly applicable to people's lives. We hope to get the public excited about climate science by demonstrating that this is something we can participate in together while achieving something truly great.

Ultimately, the International Climate Year will be a success if the global perception of the climate change problem can be permanently altered. For at least thirty years, the message of climate change has been one of fear and helplessness. The global community, both politically through events like COP26 and scientifically through organisations such as the IPCC, can address this issue by inspiring hope and encouragement while engaging the public. We here propose the International Climate Year as a means to achieve this and announce to the world that from this moment, humanity will fight to maintain our home.

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The role of university education in driving equality and sustainability

Universities are often lauded as key stakeholders in addressing global challenges, such as COVID-19 and those outlined in the Sustainable Development Goals. However, the focus usually remains on the research conducted by these institutions, rather than their potential contribution as sites of education and the subsequent impact of their graduates. This is a missed opportunity given the large numbers of students attending universities worldwide. A recent report by the Organisation for Economic Co-operation and Development estimated that the number of graduates among 25 to 34 year-olds worldwide will more than double to 300 million by 2030. With such a scale of influence, we believe that universities have a unique role to play in ensuring that our populations have the skills, knowledge and attitudes to make the world a better place.

Historically, universities were "ivory towers", educating a minority of privileged people in traditional academic subjects; indeed, in some areas of the world, notably in lower income countries, this is still largely the case. More recently, many countries have moved to a different, but similarly individualistic model, in which the primary motives for degree-level education are the prospect of stable and well-paid graduate employment and a positive student experience. While this change has increased access to higher education and a subsequent increase in the average income of graduates, it has also led to (and indeed is caused by) increased marketisation and privatisation. This fundamentally changes the nature of the interaction between student and university. As students are often seen to have "paid" for an education in a transactional way, achieving the necessary grade to enter a particular career or profession may be prioritised over the development of knowledge and skills.

In this article, we propose that we need to move to a "third way" in which a university education is considered to be an opportunity to develop individuals who can effect positive change in the world. As such, the actual learning outcomes of the degree, both in terms of the knowledge learned and the skills developed, becomes more important than achieving a threshold grade, because these attributes enable graduates to make a difference. This is not a new concept; universities have for decades provided a platform for societal transformation, including the civil rights movement, feminism, and gay liberation. Our proposals build on the work of Marginson (2011) who considers the role of universities in terms of the 'public good". He argued that universities operate like Habermas' Public Sphere: a site somewhat between the state and civil society. They provide a space for discussion, debate and criticism, often directed at the state and which constantly generates new ideas and strategic directions for states and governments to consider, contributing to the renewal and reform of society. However, traditionally, these have usually arisen through informal networks and actions pursued outside the main curriculum, rather than as a core raison d'être of the experience.

We believe that the collective benefit of higher education itself surpasses the individual. There is a 'public good' which has political and socio-cultural dimensions and which reflects our vision for our world. The UN Sustainable Development Goals provide a timely opportunity for a renewed focus on higher education to promote social and values-based education.

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The role of university education in driving equality and sustainability

Our proposal is that Universities educate students to be future thought leaders and agents of change for a sustainable world. We believe that there are three broad categories of change needed in tertiary education to promote this agenda. Firstly, in addition to their specialist professional knowledge and skills, students need to be educated to have influence and impact. Students need evidence-based, and culturally-informed knowledge of the social and environmental threats to our world and the skills to diminish these threats. It is important to note that these skills also promote employability, which is repeatedly identified as a key driver for university attendance. Employers have been calling for graduates who are creative and innovative with transferable skills for collaborative problem solving in complex and shifting contexts. Focusing on these skills will educate graduates for career excellence and a global contribution. Secondly, students need to understand systems and structures that are the root causes of social and environmental damage. They need the capacity to operate upstream, preventing issues, rather than working downstream on problems, once damage has been done. Preventing social and environmental damage is as important as learning how to mitigate established concerns. Finally, education needs to explicitly encourage students' civic skills, global citizenship and leadership, supporting their identity as political beings with stewardship for social, environmental and economic protection. It is essential that graduates recognise that they have the expertise to be effective advocates and influencers for change, both within their professions and social communities. With informed ethical leadership graduates can intentionally influence the global agenda and have meaningful and profound impact for a healthier earth.

It is important to emphasise that all academic disciplines have the potential to positively impact global challenges and social development. For too long, the focus has been on science, technology, engineering, mathematics, and medicine (STEMM) subjects. While many solutions for key issues will inevitably be driven by technological innovation, the role of arts, humanities and social sciences should not be underestimated. History, theology, and social policy help us understand how communities behave and likely consequences of these responses; in turn, literature, art, and music help us navigate the human condition, enhancing well-being and creating social change. We believe that the real power is at the intersection between subjects; for example, a project at the University of Birmingham that brings together the arts and nursing to explore loss, grief and bereavement. Similarly, COVID-19 has demonstrated that it is impossible to separate the influences of health, the environment, and economic policy and that to have true impact, we must understand, and be able to work at, this nexus.

A further way in which higher education can enable us to address global challenges is through the opportunity to develop intercultural understanding and collaboration. Cultural diversity within the classroom and university community is now the norm rather than the exception in modern universities. At an individual level, this gives the potential for students and graduates to develop global perspectives and intercultural competency that prepare them to work in and influence the modern global and interconnected world. Strategies to promote internationalisation in higher education have focused on increasing numbers of international students and building opportunities for international mobility. While these are examples of mechanisms of internationalisation, they do not in isolation guarantee that students develop an understanding of the dynamics and power interactions of multicultural settings nor how they can modify their own beliefs and behaviours to function as responsible professionals in a global workplace. Instead, higher education institutions must develop strategies to promote purposeful and inclusive integration of students from all backgrounds, to enable the development of true intercultural competence and understanding.

Universities are also institutions grounded in their local area, acting as anchor institutions for their communities. Too often, the emphasis of discussion around global challenges, and in particular inequality, is portrayed as a discrepancy between high income and lower income countries, yet inequality is a local issue everywhere. The historical cultural assumption that inequality does not exist within our own communities is too often impeding progress by allowing ignorance surrounding an issue to continue. Encouraging our students to engage with their local communities, and indeed question their own personal opinions and bias can be where conversations about global inequity start. In examples provided by the students from around the world who helped author this piece, this could involve students at Mexican universities discussing the LGBT rights movement or gender representation in their area; or those from Glasgow exploring why there is one of the largest life expectancy discrepancies within a city and why health inequalities are rising; or those studying in Johannesburg considering why there is such high unemployment among highly qualified young people. Increasing students' awareness of local social and economic issues can be the catalyst for change. We hope to demonstrate to students, and in turn graduates, that anybody can be a social agent of change. We want our students (and indeed our staff) to understand that whilst one person cannot do everything, everybody can do something if they take the time to listen, learn and apply their skills collaboratively.

To enable such a change in the focus of higher education, we must start at primary and secondary education and support children to change the way that they decide whether to attend university and, if so, which subjects they study. At present, students typically choose subjects that they enjoy and that they are good at, with some consideration of what job they might like to do afterwards; the balance of emphasis here may of course vary and to some extent be culturally driven, but it is largely influenced by the beliefs of parents and teachers. We propose working to change this narrative and instead encouraging young people to consider what change they want to see and recognise what part they can play in the development of a sustainable world. University then becomes a route to manifesting that change and young people would choose subjects that would enable them to effect this change. A cultural shift of this magnitude requires strong role models who can change attitudes locally. Educating prospective university students about sustainability and the benefits of social capital rather than individual earnings before they apply to higher education is important. Given the number of university students around the world such a change in attitude, even in only a fraction of the students, would have a significant impact. We need to start marketing higher education in terms of sustainability and to make sustainability something that counts.

One challenge in such an ambitious proposal is how to implement this level of change. It is clear, however, that external drivers can promote university action for positive change. When the United Nations introduced the Sustainable Development Goals in 2015, they noted that universities had an important role in achieving the goals. In 2019, the Times Higher Education (THE) Impact Ranking of universities was launched specifically to encourage universities to take action to achieve the 17 goals as well as measuring their progress towards this. Consistent with our recommendations, THE specifically called for education to support students to learn how to deliver and embed the SDGs in their future careers, clearly articulating that universities must educate for change. This ranking system has proved popular with 450, 768, and 1,115 universities respectively seeking assessment over the three years, demonstrating a rapidly increasing number of universities choosing to be involved with the ranking. While this league table has been criticised as driving competition between universities and having some methodological limitations, it does provide incentive for action. It articulates indicators of how universities can powerfully contribute to the social, environmental and economic protection of all life on the planet. It allows universities to compare their performance and encourages innovation and better practice to improve scores over time. It now operates as a globally recognized guide and measure of the societal contribution of universities. With annual reporting of outcomes, universities can be motivated to take purposeful action with greater accountability within the public domain. Visible global benchmarking activities acknowledge and reinforce that universities must be ethical and responsible corporate citizens, leaders and actors for positive change. However, given that there are an estimated 18,000 higher education institutions worldwide, a considerable shift in thinking is required to ensure that all are placing sustainability at their core. Furthermore, future iterations of the rankings should more explicitly include curricula content and also encourage more collaborative partnerships between institutions.

We recognise that our proposal represents a sharp change in direction from the way universities and other higher education institutions tend to operate at present. To facilitate this move, faculty training and recognition needs to align with an aspiration to develop the social capital of communities. Lecturers and researchers currently focus on specialist or measurable outputs (research articles, percentage of students finding employment, student satisfaction rates) motivated by the need to generate individual human capital. Similarly, faculty are recognised and promoted based on individual achievements (publications, positions of esteem, teaching awards). Researchers and lecturers receive increasing, but still minimal, pedagogic training and the training provided is focussed on delivering specialist knowledge and skills and promoting "student engagement" with the discipline itself. Without prior experience of developing a social rather than human capital, faculty need to develop their teaching to incorporate the development of these skills and attitudes in their courses. They must be encouraged and enabled to explicitly discuss and model societal investments of their time and effort. To encourage faculty to take part in such a sharp departure from their normal activities, reward and recognition systems need to be updated. In the same way that the introduction in some countries of a mandatory requirement to hold AthenaSWAN status to obtain research funding led to nationwide improvements in gender equality, policymakers need to encourage institutions to develop cultures which encourage the development of social capital. This would drive a change in promotion criteria, create recognition for good practice, and lead to much needed funding for such initiatives.

To conclude, we believe that universities are unique institutions, full of able and motivated students who have the potential to lead us in the future to a better world. We need to ensure that the higher education sector, potential students, and society more generally, recognise the opportunity that higher education provides to develop communities of skilled, thoughtful and inclusive citizens, and that we structure our programmes to ensure that sustainability, in its widest sense, is at the heart of our purpose.

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The impact of militaries on climate change

One enormous area of oversight when addressing the climate challenge problem is the vast contribution of national militaries to pollution and greenhouse gas emissions, especially in western democracies. It has been estimated that 20% of all environmental degradation globally is due to military-related activities (Angus, 2016). A 2020 report by Scientists for Global Responsibility (SGR) and Declassified UK found that the UK military-industrial sector produced the equivalent of 6.5 million tonnes of carbon dioxide, which was greater than the CO_2 emissions of 60 other countries (Parkinson, 2020). Meanwhile, the United States' Department of Defense (DOD) is the world's largest institutional consumer of petroleum and the world's largest institutional producer of greenhouse gases (GHG), producing over 3,685 million metric tonnes of CO_2 between 1975 and 2018 (Crawford, 2019). In a similar fashion to the UK, US military emissions alone are consistently larger than the entire output of other industrialised nations, with the Pentagon's greenhouse gas emissions outweighing that of Sweden, Denmark and Portugal and GHG emissions from the DOD are also greater than all CO_2 emissions from US production of iron and steel (Crawford, 2019). Largescale military emissions are also not limited to the Anglosphere, with another SGR report suggesting that the combined militaries of the world contribute to 6% of the global carbon footprint total, with China, Saudi Arabia, Russia and India being likely large contributors, but are much less transparent on their statistics (Parkinson, 2020).

Causes of emissions

Thus, one must ask, how did such a costly situation arise? Perhaps the most obvious reason is what Joshua Reno in his book 'Military Waste' called "permanent war-readiness" (Reno, 2020), with a heightened international climate in the wake of 9/11, the US military produces a sizeable amount of GHG emissions just from the maintenance of its forces. Indeed, operational energy, or what the DOD defines as "energy required for training, moving, and sustaining military forces and weapons platforms for military operations" (Office of the Assistant Secretary of Sustainment, 2018) accounts for 70% of total US military energy consumption (Crawford, 2019). The constant demand for sustaining a worldwide military presence not only impacts the climate in terms of greenhouse emissions, but the human health cost of these military operations are also considerable. Studies conducted near the Basra military base in Iraq (pictured in Figure 1) found that rates of babies being born with birth defects were as high as 30% in 2010, and more than 85,000 US Iraq War veterans were diagnosed with respiratory problems (Vidal, 2016). These pollution issues are linked to the constant state of war-readiness; with the US military constantly operating 'burn pits' as an inexpensive means of destroying waste whilst on deployment. Iraq War veteran Joseph Hickman recounted that soldiers would sleep less than a mile away from 270 'burn pits', which incinerated items such as explosives, faeces and electronics twenty-four hours a day, with some still burning to this day (Hickman & Ventura, 2016). Hence, a major contributor to damage to the climate caused by militaries is the fact that armed forces require perpetual upkeep, resulting in militaries choosing cost-effective and heavily polluting solutions to problems such as waste removal whilst on deployment, leading to both air pollution and human health hazards.

Figure 1: Map of Iraq, with Basra in the corner. Levels in lead in teeth and baby birth defect rates were found to be abnormally high in this region, which is near a US military base. Map data © 2021 Google.

Hickman claimed that no regulations existed about what could be burned, which gives an insight into the second major facilitator of military emissions, lack of effective national and international policy. Military actions were made exempt from the 1997 Kyoto Protocol emission targets and the US won an exemption from emission limits for "bunker" fuels (dense, heavy fuel oil for naval vessels) and all greenhouse gas emissions from military operations worldwide (Angus, 2016), hence demonstrating a clear lack of concern for the impact of militaries on the climate. Worse still, the Kyoto Protocol was not even ratified by the US, and in 1999 the House of Representatives further protected the US armed forces from acting on its carbon GHG emissions with a National Defense Authorization Act (United States Congress, 1999). Moreover, the Russian military has published no plans to reduce its own GHG emissions (Brzoska, 2012) and although NATO adopted the Green Defence Framework in 2014, which was set out to improve energy efficiency, the Framework does not include any GHG emission, specific carbon reduction or environmental performance targets (NATO, 2014). However, a plethora of high-ranking officials have continuously made statements about the threat posed by climate change and the need to reduce GHG emissions despite the bizarre lack of action on their behalf. For example, despite the Ministry of Defence's (MOD) aims to reach net-zero emissions by 2050 (Ministry of Defence, 2020) and the MOD laying out GHG reduction plans in the Climate Change Delivery Plan 2010 (Brzoska, 2012), the new HMS Queen Elizabeth and HMS Prince of Wales will carry 36 of the new F-35 Lightning II combat aircraft, which consumes 60% more fuel per flight hour, thus producing much greater emissions, than its predecessor, the F-16 Fighting Falcon (Peck, 2019). In China, a similar disparity between statements and concrete action has emerged; the People's Liberation Army general staff have set up expert commissions to study the potential national security consequences of climate change, yet there have been no authoritative statements made by the army on the issue, and when climate change was debated at the UN Security Council in April 2008 and July 2011, the Chinese representative rejected the notion that the Security Council should consider climate change (Brzoska, 2012). Hence one of the main reasons for unchecked military emissions becomes apparent – policy and corresponding measures to reduce carbon and GHG emissions are not aligned, allowing militaries to effectively bypass the desires of the public and international community.

The final reason for the unchecked growth of military emissions is the role of military-industrial complexes in arms production. In the US, defence contractors such as Lockheed Martin and Boeing fight to secure contracts to manufacture vehicles for the military, by either lobbying politicians directly, or by promising jobs in said politicians' home states. As a result, politicians are inclined to support projects such as the F-35 Lightning II, despite it being 70% over budget and aforementioned fuel consumption issues (Shalal-Esa, 2013). Hence the US military-industrial complex alone produces over 153 million metric tonnes of carbon pollution annually, on par with the total emissions from the Netherlands (Kahn, 2019). This problem is not exclusive to the US, with the UK's MOD contractors having a poor record on the management of radioactive waste, with companies such as Sellafield Ltd receiving multiple fines for breaching of environmental regulations, but no long-lasting public consequences (Parkinson, 2020). Hence the complex relationship between politicians and defence companies means that elected representatives are often encouraged to turn a blind eye to environmentally costly projects in favour of political gain.

Combatting military emissions

The question then arises, how does the international community begin to combat these emission problems? The most trivial and obvious solution comes in the form of massively scaling back military budgets; proponents of the Green New Deal in the US have demanded for the military budget to be slashed in favour of increased spending on environmental projects. Closing overseas bases, such as the approximately 800 facilities currently operated by the US (Vine, 2015), would go a long way in cutting emissions; this would also benefit France in particular, which has nearly double the military carbon footprint of Germany because of its numerous overseas deployments (Cottrell & Parkinson, 2021), as well as the UK, which has 20% of the Royal Navy's operating fleet deployed to the Middle East at any one time (Parkinson, 2020). However, the implementation of drastic cuts to military budgets would require significant political capital, and hence the remainder of this article will discuss other solutions to this problem.

The SGR group recommends an improvement in the collection and presentation of Sustainable MOD environmental data, which has been error-strewn and lacking in clarity in recent years (Parkinson, 2020). For instance, for the financial year 2017-18 the MOD quoted that their direct carbon footprint was 0.94 tCO_2e (million tonnes of CO_2 equivalent), yet proper investigation uncovers that these numbers are only related to 'Estates' and 'Business travel'. The SGR report calculated that the true emissions figure was 3.03 tCO_2e, over three times the reported amount (Parkinson, 2020). A different report published by Brown University recommends a similar course of action for the DOD, advising that the department should report its fuel consumption to the US Congress in both its budgetary submission and in a separate annual fuel consumption report, as well as ensuring that this data is complete and well organised by disaggregating its data into fuel type, service, year etc. as well as including emissions from training missions and public displays (Crawford, 2019). Hopefully, this will persuade other major global powers to do the same, such as Germany, who currently does not make their carbon emissions data publicly available (Fort & Straub, 2019). Overall, encouraging armed forces to publish more comprehensive data on their impact on the climate would not only make militaries and governments more accountable to the public for their role in climate change, but it would also allow environmental groups to make better suggestions for areas of improvement. Publishing more data on emissions would also help voters recognise the dangers of military-industrial complexes and apply scrutiny to politicians who defend the manufacture of new, environmentally damaging military hardware.

It is also crucial for government policy and military initiatives to be aligned. As discussed before, whilst governments have appeared to make steps in combatting climate change, armed forces are far too frequently exempted or overlooked. SGR recommends ensuring that GHG emissions from UK military operations are limited by the Climate Change Act, and indeed UK military strategy as a whole ought to be shifted from long-range, environmentally detrimental 'force projection', to a strategy that primarily focuses on territorial defence (Parkinson, 2020). The US can follow suit by ensuring that the military is included in President Biden's plan to cut national carbon emissions in half by 2030 (Newburger, 2021). As for global targets, whilst the Paris Climate agreement did not exempt national militaries from emission targets, it did not make countries legally obligated to reduce military emissions either (Nelsen, 2015). A revised global agreement which completely closes this loophole is crucial in making a coordinated effort against military pollution and ensure that military emissions remain relevant in future climate summits.

Finally, a renewed focus on research and implementation of fuel-efficient and low carbon technologies would be beneficial to both militaries and the environment. Although existing jet fighters could potentially be adapted to use 'drop-in' sustainable fuel sources such as biomass and household waste, which would cut Royal Air Force CO2 emissions by 18% (Wallace & Shapps, 2020), these climate considerations appear to have been treated as an afterthought, with vehicles being adapted after several years of service instead of eco-friendliness being a core principle in vehicle design. Whilst the MOD has done taken action to reduce the carbon emissions of some of its building (Parkinson, 2020), more research is required into the environmental costs of manufacture and usage when designing new weapons and equipment, which hence limits the damage to the environment, and keeps consumption costs lower for militaries. However, SGR also notes that military climate initiatives ought to be treated with scrutiny, such as the US Defense Science Board's More Fight, Less Fuel program, which is simply a misguided scheme with the aim of fighting wars more efficiently (Parkinson, 2020). Therefore, militaries must put climate change at the top of their agendas when considering which new technologies to invest in.

In conclusion, the impact of armed forces on climate change and carbon emissions is both broad and frequently overlooked, with ramifications for both human health and the environment. Their greenhouse gas and carbon emissions have been allowed to rise due to the global presence and constant state of war-readiness, unthorough government and international policy, and the power of military-industrial complexes, which result in politicians defending environmentally hazardous military projects. However, this situation is not irreparable, and by taking the advice of independent groups such as Scientists for Global Responsibility, ensuring that government policies and military actions match, demanding greater transparency and more data on military emissions, researching new, climate friendly technologies and potentially scaling back overseas military presences, emissions from armed forces can reach more sustainable levels without the need to make drastic cuts to military budgets.

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Strengthening the climate resilience of households in the Sundarbans

Recent decades have witnessed an increase in climate change related losses and damage. The evidence suggests that there has been a fourfold increase in the incidence of disasters. Hydro-meteorological disasters are the most common type of disasters globally. Furthermore, climate researchers have warned further that frequency of extreme events will rise leading to an increase in the number of disasters worldwide. At least 207 natural disasters were recorded globally in the first six months of 2020, well above the 21st century average (2000-2019) of 185 disasters. These disasters cost the world $75 billion, according to the Aon catastrophe report, released in July 2020. At least $71 billion, over 95 per cent of the loss, was due to weather-related disasters. In fact, around 92 per cent of these disasters between January and June were weather-related. There were 14.6 million new internal displacements across 127 countries in the first six months of 2020.

Coastal areas are particularly vulnerable to increasing risks of erosion due to sea level rise. These will be further worsened by the human-induced pressures. By 2080, millions of people in the densely populated mega deltas of Asia will regularly experience floods. Poor households, communities with climate-sensitive livelihoods and those living in coastal and river flood plains will be most vulnerable, and the impacts will shape the well-being of the communities, their education and skills, socio-economic development, infrastructure availability, and health outcomes. Mangrove ecosystems are particularly vulnerable to sea-level rise, amongst other climate related factors. For example, a one metre rise will completely inundate the Sundarban mangrove in the Bay of Bengal resulting in widespread damage to local ecosystems, which currently form a major base for the livelihoods of the communities that reside there.

The impact of climate volatility in low-income countries, where climate events often result in irreversible losses and impede long-term development prospects, is not being met by effective policy responses. Involving communities in development can help poorer regions manage climate change and climate volatility by empowering local people to become active agents in creative resilience. These communities need safety nets that are responsive to climatic risks and natural disasters, programmes to develop their livelihoods, and access to finance and insurance. The new wave of financing for climate change adaptation represents a unique opportunity for deploying these community-based interventions.

My work in the Sundarban suggests that policies should be reorganised and designed to be flexible with the changing climate/weather events that negatively impact the households in this fragile area, their livelihoods and communities. In times of crisis, families often have few coping options apart from drawing down on their assets. Liquidating assets in this way may help families cope in the short-term, but it comes at the expense of long-term security and adaptation. This is especially important to consider as the impacts of climate change accumulate over time, and marginalised poor households will need support in adaptation and building resilience.

Business as usual is no longer working for the Sundarban community. Strengthening resilience does not stop at identifying the factors, but moving towards actions. Firstly, we need a better understanding of resilience – going beyond merely providing relief and short-term support to affected communities. Investing in long-term resilience is key. Household-level resilience can be improved with support to allow people to build up savings and acquire assets. The Indian government already has an array of safety nets that has capacity to buffer and help build resilience of the households, such as rural employment generation schemes, and midday meals for school children. However, from the study it is evident that they do not reach those who need them the most. These policies need to be part of the larger development and poverty reduction schemes that provide increased opportunities for education, and the vocational training which is crucial for the Sundarban households.

Social protection enables rural transformation. Social welfare can promote inclusive transformation in many ways, though the evidence remains scarce at the macro level. Transformation is dependent on the capacities of the households to invest in different forms of capital. This opportunity is determined by policies and institutions combined with social safety nets through various programs to bring about an inclusive rural transformation.

Improvements in employment benefits the community in multiple indirect ways. It is well documented that empowering women economically has positive impacts on health, education, and other dimensions of human capital. Multiple benefits come with the government investing in policies that create employment opportunities for rural households. Its advantage is that there is more income available for other household needs than food. Safety nets and conditions that favour this will enable rural transformation.

FAO, 2016 suggested possible strategic adaptation interventions across sectors to build resilience of communities. These stress interventions for the water sector, in preservation of forests, in securing livelihoods and food, livestock, energy and in land use and river management.

2015 to 2016 are years of considerable importance as the majority of the governments across the globe agreed to the Sendai Framework for Disaster Risk Reduction (Sendai Framework), the United Nations Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change, and the World Humanitarian Summit Framework (WHS). These agreements and frameworks set out targets for the nations for achieving better preparedness for disasters, sustainable development and to tackle larger problems of the human world.

It is interesting to note that the concept of resilience is central in all these agreements and frameworks, along all sectors and scales. These levels and areas are critical as resilience is complex and it is important to combine efforts in directions for disaster risk reduction, sustainable development and climate change. This effort would require strong financial mechanisms, policies and programmes that can deliver on one or more targets at the same time. However, it is still at an early stage. It will take time until these global agreements are fully standardised and implemented. It would therefore still be wise to plan for the micro level, making households more resilient.

Sustainable Development Goals

Seventeen universal Sustainable Development Goals were set along with targets and various indicators for the national governmental interventions. In 2016 the United Nations Research Institute for Social Development (UNRISD), published a report called Policy Innovations for Informative Change that provides a pathway for countries to imbibe the 2030 Agenda of Sustainable Development Goals. This draws attention to the need to address the root cause of the problems and urges to rebalance social, economic, environmental sectors and processes for sustainable development. However, transformation is not possible by just making new policies or investments, the necessary condition is that it needs participation from civil society and communities which will ensure inclusive processes to make this into a reality.

Nation-led efforts that have tried to address the needs of the inhabitants through the numerous central and state government schemes in the Sundarban region. There are several projects both central and state that are similar to the universal goals and targets that are aimed for sustainable development. The best example of eco-social policy called Mahatma Gandhi National Rural Employment Guarantee Scheme, 2005 is now recognised and cited around the world. The policy integrates the social and environmental goals that ensures 100 days of employment per year to every rural household. The policy is devoted to environmental conservation, natural resources management that includes creating sustainable assets, water management and soil conservation. One of the pre-requisites to enforce the 'rights and entitlements' envisaged and make it community-oriented and demand-driven scheme. The success of the programme is entirely dependent on the participation of the community in general and women in particular since the share of latter in employment is almost 50%. The policy has benefited 20-55 million rural households and helped them come out of poverty. However, it comes with its own set of problems such as monitoring, access to resources and programmes and lower skills of the households.

With this background the study recommends that the village administration can play a crucial role in facilitating, monitoring and accessing schemes that will only push the communities and thereby the households to build resilience to natural hazards events and other weather-related shocks. Several Indian government led schemes overlap with the goals. Out of seventeen goals, ten goals correspond with the Indian government schemes, and it is possible to incorporate the remaining seven goals in the programmes. My work identifies these links and recommends strengthening the role of village administration.

Goals 1 to 3: The village administration can play a fundamental role in the identification of the vulnerable sections of the community and their needs. These exercises would ensure that families are covered and included in the Public Distribution System. It would give women, children and older adults access to food at all times. It would also promote climate-resilient agricultural practices would aid in ending hunger and achieving food security and improved nutrition for the families. Furthermore, they can ensure healthy lives and encourage well-being of the community members by regularly assessing and maintaining the quality of the health care offered, and promote awareness with the help of the health department. Currently, mental health care support is particularly lacking in the Sundarbans.

Goal 4 and 5: Sundarban families have significant education expenses. The village administration can plan for more residential schools for children, both boys and girls. It can also ease access to scholarships, textbooks, uniforms, and meals. The village council can also facilitate vocational evening courses for both school children and school dropouts. Currently, the school infrastructure is poor with substandard toilet and drinking water facilities. Girls are particularly affected by this. Village administration can promote, monitor and strengthen the quality of educational services. To achieve gender equality and empowerment to all women and girls, the village administration can promote equality through the Beti Bachao and Beti Padhao programme to save girls from discrimination and ensure their education. Providing incentives to the households to help them retain the girls in school could strengthen these. Vocational and small and medium business skills should be encouraged and imparted to girls who are not in school. In turn, this will ensure that there are skilled women that can contribute productively to the village economy. Gender equality cannot be achieved unless women are part of the planning and implementation of the current government programs in the village administration. Women are found to be better change agents of socio-economic transformation, efforts are needed to strengthen their participation for household livelihood security as well as better asset management.

Goal 6 and 7: These goals concern the availability and sustainable management of water and sanitation for all, and are thus directly linked with the health of the population. The administration can ensure that households with and without sanitation facilities should be identified and awareness created for proper use and maintenance of these facilities. Local communities should be encouraged to participate in the development and plans for implementation. Awareness and education about hand and personal hygiene should be imparted to the community alongside to prevent the spread of diseases. Water resources should be monitored for both household and agricultural use. Recharge of lakes and wells should be ensured for the provision of sweet water during difficult summer months. It is important to ensure access to affordable, reliable, sustainable and modern energy for all.

The village administration should ensure that energy provision to the households is made through a network of government-led efforts along with Non-Governmental Organisations through its programs. Sundarbans is remote, and grid transmission is challenging mainly due to its geography. Solar energy could be a more pragmatic way of supplying energy to the households. Households need smokeless cooking stoves that are both energy efficient and reduce cooking time. Women should be included on village planning committees to ensure its deliverance.

Goal 8: This goal also ties well with the development goal that lays importance in promoting sustained, inclusive economic growth, including employment of all people. Youth, both male and female, could give sufficient assistance in acquiring finance and credit from the village administration, be trained in relevant skills to start small and medium businesses. These efforts could also particularly include women and people with disabilities. Awareness is thus needed of labour laws labour rights, which could be imparted by the village administration. The corresponding current Mahatma Gandhi National Rural Employment Guarantee Scheme is contributed to this goal.

Goal 13 and 15: There is no clear plan that village administrations are responsible for combating climate change and impacts. These are national and state-level responsibilities. However, there are programs in which the village administration can play a crucial role. Most importantly, the village administration can facilitate awareness about climate change and climate variability on the lives and livelihoods of people in the community. Micro level vulnerability assessments should be conducted by the village administration along with the community to understand the impacts and needs of their community. The results from these evaluations could feed into village, state and national policy making for better mitigation strategies for livelihoods and building resilience of the communities for future events. Village administrations in the Sundarbans should promote and restore sustainable ecosystems and forests. Currently, it has been initiating mangrove afforestation drives and ensure their maintenance. Community-based management of forest areas through the Joint Forest management scheme is operational in the region. These should be further linked with Mahatma Gandhi National Rural Employment Guarantee Scheme where local species of mangroves and other tree and plant species should be promoted. Further awareness on conservation of forests should be developed, especially given the uncertainties of weather and extreme weather events.

Policy recommendations for the management of the internally displaced climate migrants

My work is mainly carried out in the transition zone (which includes the tidal zone) and the households in this area could become migrants or displaced people in the future. Sundarbans is a World Heritage Site that everyone should care for, mainly because the households are bearing the consequences of unplanned development elsewhere. It is therefore pragmatic to invest in a policy that caters to their needs.

Conflicts, political instability and extreme weather events are among the primary reasons for migration today. In 1990, the First Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) noted that the greatest single impact of climate change might be on human migration and displacement. Despite the warnings and statistics that followed, little has been done in national or global arenas to deal with climate-related migration or to bolster international capacity to handle any large-scale movements. Policy responses have primarily focused on three areas: the definition of refugees, adaptation, and resettlement.

Major climate change leads to human migration and reports say that around 24 million people across the world have become climate change refugees. These refugees are often neglected. Around 63 million people in India live in the 50 km range of coasts. Various areas are categorized as 'low elevated coastal zone' which are under threat of getting submerged because of the rapid increase in sea level. The people living in these regions face the imminent threat of displacement. The number of refugees can go up to 12 million by 2100. As per International Organization for Migration, a United Nations body, the Bangladesh coast will be impacted more than India. But this will put India in a disadvantageous position as it will face large number of migrants coming from Bangladesh.

The Disaster Management Act of 2005, makes it mandatory for every Ministry or Department of the Government of India, in centre or State, to prepare a Disaster Management Plan and accords them the responsibility of aiding in case of relief operations, rehabilitation and reconstruction after disasters. The Act ensures that the government and related authorities, both at the state and local level take "necessary measures for preparedness to respond to any threatening disaster situation or disaster". The assistance for emergency responses, relief and rehabilitation, is to be met by the National Disaster Response Fund (NDRF) and the mitigation of disasters is to be borne by the National

Mitigation Fund, along with the State and District delineations of each of the funds above. However, the Act does not have a definite plan for resettlement or rehabilitation of such displaced population by disasters. The West Bengal Disaster Management Policy (2010) states that 'relocation' must be a result of 'need-based considerations'. It does not consider factors such as the nature of the calamity, the extent of damage, consent of the affected population, land acquisition, urban/rural land use planning, relocation packages, legal authorization for relocation and rehabilitation and livelihood rehabilitation activities. The rehabilitation activities in the policy focus on the reconstruction of infrastructure, economy, agriculture, health and education.

The Food and Agriculture Organization of the United Nations (FAO) Director General Jose Graziano da Silva has stressed the need for investing in rural development and making livelihoods climate proof. He further points out that these should be an integral part of any solution to curb migration. Migration should be a choice and not a desperate act! This all holds true if the people are not located in places like the Sundarbans which have higher degree of physical risk such as flooding, sinking of the islands, salinity and sea level rise. Physical risk along with related fallouts such as social, cultural and economic make it even more challenging. Since 2016, we have seen a rise in violence in the 24 South Parganas. Many cite the influx of Bangladeshi migrants, and some cite an increase in communal tensions. We sensed this underlying tension in the villages during fieldwork. Several households are not prepared for anticipating and to cope from climate/ weather events. This will only push them into migration. In the Sundarbans region there is increased pressure on both people and the place. There is migration from Bangladesh to India in search of a better life - coming from a risk environment to another risk environment and of Indian inhabitants already in poor state looking for relief and possible migration to main land India. Therefore, there is an urgent need for a clear definition on who is an environmental refugee and internally displaced people and who will bear the costs of their rehabilitation and resettlement. The Indian Government should prepare itself with local-regional and bilateral frameworks to prepare itself for this burden in the region and within the country.

India has a long history of rehabilitation and resettlement of people and have supported political asylums and refugees from neighbouring countries and have resettled some people within the country. An example of this the resettlement and rehabilitation of inhabitants from the Lohachara island in the Sundarban. The total number of resettled people is between 4000 and 7000. However, it lacks a framework or policy for internally displaced people, or any bilateral agreement with its neighbours for environmental/climate refugees.

Weather events and climate change are a global phenomena and the burden of costs for management and rehabilitation for climate refugees should be borne by the United Nations under the Adaptation fund through the Intergovernmental Panel on Climate Change (IPCC). Further, there is a need to accelerate technical assistance, knowledge and expertise through the Santiago Network. However to support the sustainable development agendas there is an urgent need to recognise the costs of climate induced loss and damage and devise a global costing and funding mechanism to pay for the losses borne by the most vulnerable communities in the global south. It would be helpful to explore seasonal migration routes and livelihoods Skill based rehabilitation. A land tenure system should be set by India, local inventory of inhabitants - land loss by erosion should be covered by insurance under the Adaptation fund. Government insurance scheme for climate events such as cyclones should be considered.

Regional bodies should be urged to adopt declarations and conventions on internally displaced person (IDP) citing the African union convention for the protection and assistance of internally displaced persons In Africa also known as the Kampala Convention as a model and promote implementation of these instruments. The Declaration should also urge governments to adopt national laws and frameworks based on the Guiding Principles on Internal Displacement and develop country strategies – together with donor governments, international humanitarian and development organizations, civil society and internally displaced person (IDP)'s themselves – to implement the agreed goals and work toward resolving displacement situations. In view of the imminent risk of accelerated weather/climate change induced mass migration/internal displacement, there is a need for immediate formulation of relevant comprehensive policies. Dedicated resources should be mobilised for the preparation and implementation of phased relocation plans for the vulnerable, while lead-time is still available. Furthermore, the study call for a global consensus on definitions and a decision framework for ensuring the responsibility for, and the rights of, environmentally displaced people in the future.

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Nature

02

Not just standing there: the carbon utility of established forest

Unlike buildings, grown trees don't 'just stand there'. Before we consider the communities supported by mature trees, we should recognise the active nature of the trees themselves. More like whirlpools than buildings, trees continually exchange energy and material with their surroundings. Trees use sunlight to create order out of the chaos of the air and earth; tempting a scientist to call them the ultimate entropy deniers. By appreciating that trees must continually run to stand still, that forests are complex plant-animal-microbe systems rather than simply a bunch of 'carbon sticks', we gain a much more complete understanding of how standing forests have a significant influence on the flows of carbon, water, nitrogen, and other nutrients through the Earth system.

When we consider the global CO_2 budget it's important to note the distinction between emissions, which are largely driven by socio-economics, and sinks, which have a very strong biological component. Only a bit less than half the CO_2 emitted into the atmosphere stays there; the rest is taken up by the ocean surface and the terrestrial biosphere. The research consensus is that the land carbon sink is bigger than the ocean sink. Currently, the northern hemisphere is taking up billions of tonnes of carbon, and the most important landscape for this uptake is temperate forest.

In the far north, the vast boreal forest may be taking up 0.5 billion tonnes of CO_2 per year but, further south, temperate forest biome is taking up 0.8 billion tonnes, which is equivalent to all the emissions from the EU 27 nations plus the UK, or approximately the amount of CO_2 released from deforestation globally. This is a huge number, worth almost £15 billion at today's carbon trading price and much, much more in reality. The countries of the temperate zone – between the 30th and 50th parallels, very roughly, and encompassing the great majority of what is often called the Global North – are in an ideal position to lead in the adoption of practical measures to maintain and maximise the land carbon sink. Activities to maintain stocks of, and increase flows into, land carbon should recognise the three great forest biomes (tropical, temperate, boreal) and fit policy options to each.

What we know

The land carbon sink is important now; how it reacts in future is critical to our climate projections. The Intergovernmental Panel on Climate Change (IPCC) recognises the CO_2 feedback on the land carbon sink as the most important feedback in the carbon cycle.[1] 'Feedbacks' are the accelerator and brake pedals of any complex system such as climate. Positive feedbacks accelerate change; negative feedbacks, like that of CO_2 on the land carbon sink, resist change. The CO_2 feedback on the land carbon sink is often called "CO_2 fertilisation" and is currently providing a very significant, but far from total, brake on global warming. CO_2 fertilisation cannot now, and never will, offset entirely historical fossil fuel use and save us from global warming — not for the UK, and not for the world. Nevertheless, a key question for our climate projections is whether CO_2 fertilisation will continue to provide its current planetary free gift, whether it will provide an even larger brake on climate change as CO_2 levels increase further, or whether it will begin to decrease in importance as factors other than the CO_2 level begin to dominate forest responses.

Currently our understanding of how temperate forest will respond to elevated CO_2 is based largely on the first-generation forest Free-Air CO_2 Enrichment (FACE) experiments, for example, the experiment in Sweet Gum in Oak Ridge, Tennessee, or the experiment in Loblolly pine in North Carolina. All of these experiments were in young plantations

[1] Ciais et al 2013. In: Climate Change 2013. The Physical Science Basis. Cambridge Univ Press. (Fig 6.22). https://www.ipcc.ch/report/ar5/wg1/

growing in non-forest soils and so, for those parameters derived from FACE experiments, climate modellers are predicting the response of the world's forests based on the responses of young plantations, despite the majority of broad-leafed temperate forests being greater than 50 years old.

We know that, as forests age, competition between trees intensifies, and this is expected to result in mature trees exploring more and more of their soil resource to acquire nutrients until the soil and the forest are optimally interlocked. In this case, mature trees would not be able to use additional carbon fixed under elevated CO_2 to promote greater amounts of nutrient uptake and therefore may not be able to sustain a growth response to elevated CO_2. However, in absorbing carbon, perhaps mature trees, in the temperate forests and elsewhere, find more nutrients to take up, use nutrients more efficiently, or both? To answer this, we require detailed experiments that link the carbon cycle to nutrient and water cycles to improve our climate models. Very few models have carbon coupled to nutrients, and those models are not challenged by data (because there have been no data).

As it grows to maturity, standing forest is not undisturbed; forests continually experience disturbance from fire, flood, disease, storm, and harvest. The 'natural' disturbances are increasingly affected by human influence, including the human influence on climate.[2] Strong intergovernmental approaches to climate mitigation can stabilise the random effects of fire, flood, and storm. Strong regulatory measures can control the globalisation of invasive pests and pathogens. Moving harvest 'closer to nature' through carbon- and biodiversity-conscious management will ensure that standing forests continue to deliver environmental, social, and economic goods.[3]

The latest research

FACE facilities are the key to understanding ecosystem-level responses under future atmospheric compositions. Several small-scale facilities exist; a number of first-generation forest facilities operated at the turn of the Millennium. Only two large-scale forest FACE facilities operate currently[4], although plans for a third, in the Amazon, are well advanced. Forest FACE facilities are the largest climate-change experiments in the world (Figure 1); together, they represent a time-machine transporting the plants, animals and microbes of today's forests into the atmosphere of the 2050s. International agreement to set up and run an Amazon FACE, would send a clear message from COP26 that world leaders appreciate the substantial evidence gap we are bridging very sketchily with models.

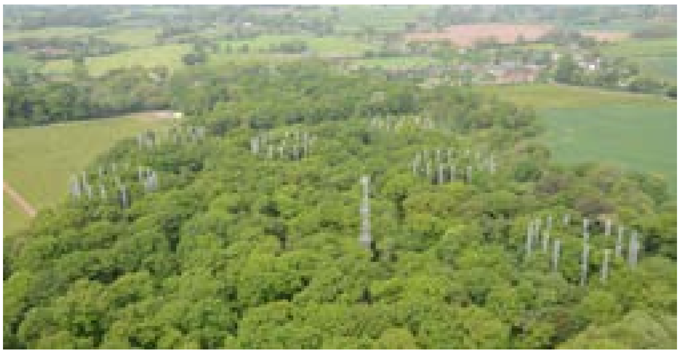

Figure 1. The Free-Air CO_2 Enrichment facility of the Birmingham Institute of Forest Research: BIFoR FACE, one of the three largest climate-change experiments in the world. Three of the patches surrounded by the metal infrastructure receive elevated CO_2 (150 ppm above an ambient level which is currently ~410 ppm). The other three, 'control', patches receive unaltered ambient air. Photo courtesy of Prof. Jo Bradwell.

How do the forests respond in FACE? The Australian facility, EucFACE, sited in old-growth eucalyptus forest outside Sydney, have produced a budget for their 'Mediterranean-type' climate and environment. Carbon is taken up when extra CO_2 is available, as expected, but seems not to be stored in this hot, dry, and phosphorus-poor environment. If there is substantial CO_2 fertilisation in standing mature forests, as our models and satellite measurements say there must be, we need to look elsewhere. A tremendous amount has been learnt in producing a carbon budget for EucFACE. The first precious data to challenge the leading climate models have been produced. The core of a forest time machine is in place; now we need to add the other great forested landscapes of the Earth to our investigation.

EucFACE has a sibling facility in cool, moist England: BIFoR FACE.[5] Although the quantitative details are yet to be peer-reviewed for BIFoR FACE, qualitatively the picture is becoming clear (Figure 2). Firstly, the forest under elevated CO_2 draws more carbon into the trees (i.e. photosynthesis is increased[6]); wood production is increased; production of leaves and fine roots[7] is increased; and secretions into the soil by the roots are increased. Ecologists say that the *Gross Primary Production* (GPP) of the forest is increased. This increased living plant mass stimulates microbial life, especially below ground, so that the respiration of CO_2 — an inevitable by-product of all life — also increases. Unless significant amounts of old soil carbon are being accessed and used up in this increased respiration (unlikely but not impossible), the carbon balance overall is that the mature forest in BIFoR FACE is drawing carbon out of the atmosphere and so helping to lessen global warming. However, until detailed budgets are produced and until the experiments

2 The IPCC "1.5 degrees" report: https://www.ipcc.ch/sr15/

3 For more information see https://www.researchgate.net/publication/260197077_Carbon_sequestration_Managing_forests_in_uncertain_times and https://theconversation.com/using-forests-to-manage-carbon-a-heated-debate-81363

4 Norby, R. J., et al., Model-data synthesis for the next generation of forest FACE experiments, New Phytologist, 2015, DOI: 10.1111/nph.13593. Note that SwedFACE, the boreal forest FACE mentioned in this paper, is not yet underway.

have been allowed to progress for a decade or even beyond, we will not be sure the degree to which this carbon uptake by mature forests is persistent.

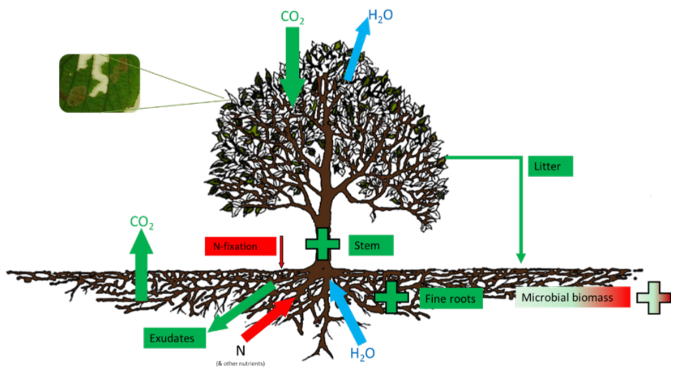

Figure 2. Qualitative assessment of the effects of elevated CO_2 on forest at BIFoR FACE for the carbon cycle (green), water cycle (blue), nitrogen cycle (red). Arrows show the direction of extra flow under elevated CO_2 conditions. 'Plus' signs indicate an increase under elevated CO_2. The inset image shows leaf mines, which are decreased under elevated CO_2 for the larvae of some species. Image from Hiclipart.com, adapted by Nine Douwes Dekker and Rob MacKenzie.

The FACE results show the land carbon sink is not straightforward and is emphatically not just a story about carbon. Our early results from BIFoR FACE show that the essential nutrient, nitrate, is less available under elevated CO_2, because the plants and soil microbes are taking up more nitrogen to balance the increased carbon that is now in their diet. A very simple analogy to this requirement for balanced uptake of nitrogen and carbon in forests is the need to balance carbohydrate (mostly carbon) and protein (high in nitrogen) in our own diets if we are to stay healthy.

If we find that mature trees cannot take up more nutrients under elevated CO_2 then it would mean that these biomes may have much less potential to take up carbon in the future than we are currently relying on, which would have massive consequences for the fight against climate change. The potential for carbon uptake by terrestrial ecosystems in the future would have been severely overestimated. According to one study, accounting for nutrient availability limitations added 15–150 ppm to atmospheric CO_2 concentration or, equivalently, 0.14–0.6oC to the global mean surface temperature change at 2100.

If future carbon uptake by mature temperate forests were confirmed to be limited by nutrient availability, the forest-based CO_2 removal techniques relied on in the IPCC's "1.5 degrees" document would be called into question. Much deeper cuts in allowable emissions of CO_2 (equivalent to 8-33 years of emissions at current rates) would be required, with profound policy and societal implications. We need to know what future we are facing, and forest FACE facilities are the only way to probe this future experimentally.

The climate crisis is not the only global environmental challenge: a mass extinction is in progress for not-unconnected reasons. The world's standing forests are intensely diverse[8], particularly when left close to their primeval condition or restored to provide multiple ecosystem services resiliently. Whether storing more carbon or not, accelerated cycling of carbon and nutrients through the forest has profound implications for forest food webs and biodiversity. Increasing GPP in a forest is like increasing GDP (Gross Domestic Product) in a country: things are bound to change. In BIFoR FACE, for instance, some leaf-mining grubs seem to do less under elevated CO_2. These grubs are moth larvae that feed on the trees' photosynthetic apparatus, the leaf, and are themselves parasitized by wasps. Other work in BIFoR FACE will investigate the implications of the changed nutritional quality of leaf litter on the forest floor food web and the impact of elevated CO_2 on decomposition of deadwood by fungi and invertebrates. By recognising fully the carbon utility of standing forest, the international community will also provide essential knowledge to help prevent a biodiversity catastrophe.

So, nature-based solutions to climate change are not all about tree planting. Afforestation can never solve our problems with carbon and climate, even if we reinstated every terrestrial landscape to its most-treed extent. Working with nature strongly implies protection of, and care for, our standing forest, moving beyond the existing recognition of reducing emissions from deforestation and forest degradation in developing countries to value all mature forest. In absorbing carbon, do mature trees in old-growth forests take up more nutrients, use nutrients more efficiently, or both? The answer to this question will unlock the CO_2 fertilisation conundrum and make our climate projections much more robust. Whatever the answer, let's protect, expand, and manage our forests for their true value, not because we wish they would do the hard work of emissions reduction for us.

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[5] Hart, K. M., et al. Characteristics of free air carbon dioxide enrichment of a northern temperate mature forest. Glob Change Biol. 2020; 26: 1023– 1037. https://doi.org/10.1111/gcb.14786

[6] Gardner A, et al., Is photosynthetic enhancement sustained through three years of elevated CO_2 exposure in 175-year old Quercus robur? BioRxiv preprint 2020: https://biorxiv.org/cgi/content/short/2020.12.16.416255v1

[7] Ziegler, C., et al., Quantifying carbon fertilisation of root biomass production from elevated CO_2 in mature temperate deciduous forest. BioRxiv preprint 2021: https://www.biorxiv.org/content/10.1101/2021.04.15.440027v1

[8] See my recent overview talk: https://derby.cloud.panopto.eu/Panopto/Pages/Viewer.aspx?id=8620142d-9d03-49f5-81d0-abc900cf1809 and a short radio interview: http://birminghamtreepeople.org.uk/bifor/

Tree susceptibility and resilience to pests and disease

Trees, like all other organisms, experience a lifecycle. Starting from a seed, the seedling emerges from the earth and grows in size, reliant on the water and nutrients in the ground and on sunlight for provision of energy (sugars) via photosynthesis. This process means that the trees are creating nutrients in themselves whilst also depositing other nutrients into the earth from root exudates, fruit and seeds, leaf litter and bark. Over the millennia, trees have therefore attracted a wide range of fauna to tap into their tasty offerings as well as offering a haven for shelter (animals) or as a 'birthing station' (e.g. insects bury their eggs in the bark or leaves).

Naturally, humans have also been attracted to trees for various resources such as timber for construction, fuel for fires, sap for rubber, and seeds and fruit for food. In many cases, we have artificially selected trees for traits that are beneficial to us, for example gaining food of a particular quality, and in quantity, and thereby growing trees as crops (apples, pears, cherries). We have also planted trees for ornamental purposes (horse chestnuts and planes) and for timber production (pine, fir, spruce and larch).

Like human bodies, whose cellular content is at least half microbes, trees are not typically sterile entities. They will usually have microscopic organisms surrounding their roots, all over their surfaces and deep inside their tissues. In most cases, these are mutual interactions with partnerships between the microbes and the tree – exchanging nutrients between one another, much like an exchange of sweets in the school playground. We are also starting to realise that microbes living inside trees can do remarkable things like utilise greenhouse gas (GHG) methane. This discovery emerges from the realisation that microbes in the soil can create methane gas, which dissolves in water just enough to pass through the tree root system and through the trunk to the atmosphere – methane utilising microbes can access this methane to help them grow. Trees are of course also responsible for sequestering huge amounts of carbon, thus representing a vast carbon and greenhouse gas sink.

However, we are now observing a nexus of problems for trees particularly with the widespread emergence of pests and diseases. In the UK, the most prominent disease in recent years was Dutch Elm Disease that absolutely devastated the UK elm population. This disease is caused by a beetle that carries with it a fungal pathogen. More recently, Ash Dieback Disease (ADD, caused by the fungus *Hymenoscyphus fraxineus*), Acute Oak Decline (AOD, caused by a bacterial consortia) and Horse Chestnut Bleeding Canker (HCBC, caused by the bacterium *Pseudomonas syringae pv. aesculi*) have also been shown to be widespread within the resident tree population. The increasing incidence of these diseases can be attributed to a range of factors, unfortunately all linked directly or indirectly to human activities. Trade and the exchange of live plants and wood products spreads pests and diseases throughout the world. The introduction of a new disease (by humans) can be exacerbated by our changing climate. For example, warmer winters allow insect populations to continue to grow and cause more serious disease outbreaks when spring arrives. Changes in seasonality can also allow insects/pathogens to expand their ranges into regions that previously did not need to worry about these pests. Finally, alterations in precipitation, and especially periods of drought, can make trees more vulnerable to both introduced and endemic pathogens.

The way in which we grow trees and use once-forested land for our own purposes (city expansion, agriculture) has reduced the absolute numbers and diversity of trees that are grown. We have also dramatically narrowed the gene pools of commercially grown trees by strongly favouring monoculture (growing trees that are essentially copies of each other). Classic examples would be extensive forest clearance in the Amazon for soybean and cattle farming and in South East Asia for oil palm plantations, spanning approximately 3-5 million hectares (larger than Belgium).[1] The large scale of these clearances and subsequent loss of ecosystem services has a direct negative impact on planetary health, as these smaller forests are unable to support the fauna (biodiversity) that depend on trees and, of course, the loss of carbon and GHG storage. Moreover, the spread and emergence of pests and diseases further exacerbates these issues, especially in monoculture systems because diseases can sweep through the entire crop. Severe disease outbreaks in tree plantations or forests do not only result in tree death but also have knock-on effects to release more GHG, pollution, and increase the risk of flooding and fires. A UK "rush to carbon" that focused on extensive planting of fast-growing clones would be making a similar mistake: forsaking a healthy and biodiverse forest for a single-minded, but highly vulnerable, goal.

Future predictions on the impacts of pests and disease suggest a worrying outlook for humans and wildlife.[2] Climate changes will no doubt be a major part of this problem, for example, imagine that the UK sits in a temperate zone, but current climate predictions indicate that the typical London climate will change from its current status to be more like Barcelona in 2050. This is just one example of how climate is predicted to change in one part of the world – globally, it is clear that big changes are on the way. What does this mean for trees in the context of pests and diseases? And how do we study this and try to make the necessary preparations and changes to counter the effects. In other words, how do we make our forests resilient?

What we know

Like the COVID-19 pandemic, trees around the globe are suffering from major disease and pest outbreaks –trees are stationary and widespread, they are unable to communicate their illness, and we do not know how to aid them beyond an initial response of introducing stricter biosecurity measures. Governments around the world reacted quickly to tackle the COVID-19 pandemic. In contrast, the parallel approach for trees and forests of the world is slower, but no less important. Unlike COVID-19, however, it is not a single disease that we face but many diseases caused by a very diverse set of pathogen species.

One of the most impactful issues for trees in the world right now is the Mountain Pine Beetle (*Dendroctonus ponderosae*), which is killing huge swathes of pine trees in North American forests. In Canada, for example, an area of 18 million ha (larger than the area of England, Wales and Northern Ireland combined) has already been affected. Moreover, recent research shows that bark beetle epidemics influence wildfire severity, thus causing knock-on effects to the broader forest system. In the UK, we have outbreaks of invasive insect pests such as leaf miner (*Cameraria ohridella*) in horse chestnut and oak processionary moth (*Thaumetopoea processionea*) in oak; fungal pathogens such as ADD and red band needle blight of pine caused by *Dothistroma septosporum*; oomycete pathogens including *Phytophthora ramorum* on larch and *Phytophthora cinnamomi* in Sweet Chestnut; and bacterial pathogens, for example, AOD and HCBC. Scanning the horizon, we know that there are major pests and diseases beyond our island but close by, which if they gain entry, would threaten several native species (for example the *Xylella* bacterium towards several tree species) or severely threaten the survival of trees already under attack (the Emerald Ash Borer, for example, attacking ash trees suffering from ADD). Identifying the pests and pathogens causing disease is only the first step in designing effective control strategies to protect our native forests. Below we highlight some of the newest research that reveals the tools used by pathogens to attack trees and some novel strategies which we can employ to protect them from these attacks.

The latest research

The importance of trees has always been appreciated, but unfortunately, support for research into trees has diminished over the past few decades. With valiant efforts from colleagues in Forest Research, the Animal and Plant Health Agency and a determined group of academic colleagues, this is now changing with new funding streams from government and specific recognition of trees in the new UK Plant Science research strategy. However, trees are complex, slow growing and challenging organisms to work on, which means the scale of research, and the urgency for doing it, are major challenges. There is much to do.

A key pathway to fighting pests and diseases is to understand firstly, how pests and pathogens attack trees and secondly, how trees resist pests and diseases. This means we require detailed knowledge of how pests and diseases live, survive and spread, and especially how they attack and damage trees. In parallel, we need to examine tree genetics and physiology to identify the important characteristics distinguishing healthy, resistant trees from those susceptible to diseases and pests. Moreover, we need to know how pests, pathogens and trees perform in the 'gladiatorial arena' when the climate they live in changes.
This knowledge will help us guide practitioners on appropriate tree planting schemes and promote management practices that help trees to fight back.

The Birmingham Institute of Forest Research (BIFoR) is well placed to address these challenges, with research programmes studying disease in ash, oak and cherry as well as plant immunity, using state-of-the-art facilities at the University of Birmingham. The influence of increasing levels of CO_2 is also being studied to evaluate how this mediates physiological changes in trees, insect colonisation and disease manifestation. This is being done using trees grown in elevated CO_2 levels, using the largest temperate forest Free-Air Carbon-dioxide Enrichment (FACE) facility in the world (Fig. 1), just 60km NW of Birmingham, and our new Wolfson Advanced Glasshouses, based on the University of Birmingham campus.. A centrepiece of our research efforts focuses on the iconic oak tree, which suffers from oak powdery mildew (PM) attacking its leaves and AOD, the bacterial disease which attacks the stem.

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[2] Threats Posed by the Fungal Kingdom to Humans, Wildlife, and Agriculture.
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Figure 1. The Free-Air CO_2 Enrichment (FACE) facility of the Birmingham Institute of Forest Research: BIFoR FACE is one of the three largest climate-change experiments in the world. Pictured is one of six arrays surrounding mature trees and undercanopy; three arrays spray ambient air over the enclosed trees whilst another three arrays spray CO_2 (150 ppm above an ambient level which is currently ~410 ppm) over the trees. Photo courtesy of Prof. Jo Bradwell.

Powdery mildew, priming of oak defence and the impact of elevated CO_2

Oak trees (*Quercus robur and Q. petrea*) are a keystone tree species of the UK landscape, with ~121 million trees supporting 2300 species (not including microbes) of which 326 are obligate associates (i.e. if oak dies off those 326 species also die off). In addition to supporting these vast ecosystems, oaks are an important part of British culture and have huge economic, ecological and social relevance. For example, they are versatile and tolerant to different environmental challenges and provide a source of high-quality timber. All these characteristics make oaks excellent candidates for use in UK woodland regeneration. However, British oak woodlands suffer widespread tree loss associated with biological threats. In addition, the oak regeneration capacity is highly compromised by the extreme vulnerability of oak seedlings and saplings to the fungus *Erysiphe alphitoides*, which causes the deadly powdery mildew (PM) disease (Fig. 2). Consequently, the PM fungus hinders the establishment of new oak forests. Current methods used by tree nurseries to control the PM fungus depend on the use of chemical fungicides, which are extremely limited due to their toxicity to human health and the environment[1]. Thus, in BIFoR, we investigate the immune strategies that allow oaks to fight against the PM fungus.

Figure 2. Diseases in oak. (Right) The oak powdery mildew fungus growing on a young oak seedling in the University of Birmingham laboratories. As an obligate biotroph, it is necessary to continually maintain the fungus on living oak leaves. This allows researchers to perform controlled experiments year-round. (Left) Acute Oak Decline (AOD) in a mature oak tree, photo courtesy of Oliver Booth.

Plants, including oaks, are not docile organisms and they do react to infections by producing defensive compounds that impede or are toxic to the attacker. These defences are controlled by the plant's immune system. Plants can also make advanced preparations for potential pathogen attack by sensitizing their immune system. This phenomenon, known as priming of defence, can been understood as a plant vaccine, because after an initial stimulus that warns of an upcoming attack, plants are able to activate their immune system faster and stronger.[3] Our recent work has demonstrated, for the first time, that oak seedlings can activate priming of defence against the PM fungus. This knowledge will be exploited for the development of resistant forests, responding not only to immediate threats but also building resilience to those that will appear in the future.

[3] Conrath, U. et al. Priming: Getting Ready for Battle. Molecular Plant-Microbe Interactions 19, 1062-1071, doi:10.1094/mpmi-19-1062 (2006).

The environment, and hence our changing climate, can impact the activation of priming of defence mechanisms. A recent government statement on climate change and forestry lists different actions that are needed to ensure that the tree species planted are resilient to extreme climate events and elevated CO_2 (eCO_2). This is because, whilst it has been speculated that eCO_2 may increase tree productivity due to a carbon fertiliser effect, there are research studies that describe changes in the defensive capacity of plants after exposure of eCO_2. For instance, in soybean, studies have shown that eCO_2 leads to enhanced resistance to pathogens. However, other studies testing resistance against fungal pathogens indicate that eCO_2 does not impact resistance in ragweed and even increases susceptibility in wheat. Sadly, our preliminary observations align with the latter studies and indicate that eCO_2 results in higher levels of PM disease in oak seedlings. We have also observed that the activation of priming is compromised under eCO_2. Given our aspirations to meet carbon targets through reforestation or afforestation via natural regeneration and colonisation, these results could indicate that in the future, we will have even greater difficulties regenerating oak woodlands due to this fungus. In BIFoR, we are working hard to find solutions, including long-term strategies through assessing the impact of eCO_2 on mature oaks and their next generation.

Acute Oak Decline and oak disease immunity

The principal disease threat to oak health in the UK is AOD (Fig. 2). The defining feature of AOD is the dramatic shift in the composition of microbial communities associated with trees, moving from a balanced, healthy community to an unbalanced and unhealthy bacterial complex. Three particular bacteria (*Brenneria goodwinii, Gibbsiella quercinecans, Rahnella victoriana*) are consistently found in disease lesions and disease progression is most extensive when all three species are present. These bacteria are also detected on symptomless, healthy trees, but as part of a diverse community, potentially pointing to the opportunistic nature of the disease.

Work at BIFoR is focussed on determining the role of oak tree genetic makeup (genotype) in relation to resistance or susceptibility to AOD bacteria. It has been proposed that long-lived woody species, such as oak, are reliant on having a large and diverse repertoire of genes that deliver disease resistance (immunity) to help them survive the many years to maturity. However, to date no oak disease resistance genes have been described. Our work aims to identify oak resistance genes that provide protection either against AOD or the PM fungus. By providing this information to tree breeding programs, tree nurseries and land managers, it may be possible to select oak genotypes best-placed to be fully resistant to pathogens in their environment. Our work is therefore targeted at helping to guide planting decisions for future forests, but this is likely to take many years, possibly decades to achieve this.

Conclusion

The experience of 2020-21 and the global COVID-19 pandemic has taught us some harsh lessons about how diseases emerge and spread, how we manage them, and how to treat them. An important observation is that infections can vary from asymptomatic to acute disease to long-COVID symptoms and to death. The world has mounted a reactive response (detection, monitoring, treatments, and vaccinations) rather than a well-prepared prevention- or intervention-based response (despite warnings from scientists). The lesson for tree diseases and pests researchers should therefore be clear; study not only the acute phase of disease, but also to prepare and anticipate how climate change will influence future disease outbreaks. With this approach, we will be able to tackle pests and diseases, be better prepared to prevent them from spreading and ultimately develop future forests that are productive, sustainable and resilient. Forests that are not productive, sustainable, and resilient will not serve the Paris Agreement and could cause more harm than good to global biodiversity.

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An introduction to the statistical modelling of climate change: 1850-2020

This article is a beginner's guide to modelling climate change by statistical methods. We will see how data spanning 1850-2020 can be used to model *global warming*.[1]

In the first part of this article, we comment on graphs of climate data. These data include global temperatures, atmospheric carbon dioxide, solar activity and particulates in the stratosphere. These variables have been chosen because they are of interest to both climate change doubters and believers.

In the second part of this article, we fit *statistical models* to these data to estimate the amount by which each variable has affected global temperatures during 1850-2020. The models indicate that increased atmospheric carbon dioxide can explain 1.26 to 1.33 degrees Celsius of the temperature increase while cyclical solar activity can explain about 0.12 to 0.40 degrees of the temperature increase.

The third part of this article includes instructions on how to estimate two statistical models of climate change using an Excel spreadsheet.

A final section summarises and is followed by data and a technical appendix.

It is worth noting that statistical models (see http://www.climateeconometrics.org) are rarely used in climate modelling. Instead, *experimental and physical models* are more often used, such as the simulations run by meteorologists. In these models, the parameters are decided upon by the researcher based on various sources, such as laboratory experiments, meteorological readings or the results of *statistical models*. These physical models are then used to run simulations to verify whether the simulations closely match the observed world. In contrast, statistical models are fitted directly to the observable data to determine their parameters. Both approaches are equally valid and both produce mathematical models that can be used to forecast climate change.

The data

In this first section, we look at graphs of the climate data as a preliminary step before estimating the statistical models in section two. The Data Sources Appendix includes details of the data sources. Figure 1 shows an overall temperature increase of about 1.5 degrees Celsius since 1850. The period 1850-1940 seems one of gradual temperature increase. The Second World War was a period of relatively high temperatures but followed by a period between 1945-1964 when temperatures did not increase substantially. The period since 1965 has been one of rapid temperature increase. There are smaller year-on-year fluctuations but it is difficult to determine which of these are real fluctuations and which are measurement errors. Smoothing the year-on-year fluctuations is a bad idea because it would erase some important variations. For example, 1877 and 1878 have remarkably high

[1] Though the term global warming has fallen out of favour and been replaced by *climate change*, this article focuses on the observed increase in global temperatures and therefore directly on the warming climate.

temperatures during a major El Niño episode in what was dubbed 'the year without a Winter'. Conversely, there are some years with sudden temperature dips and these coincide with major volcanic ejecta into the stratosphere.

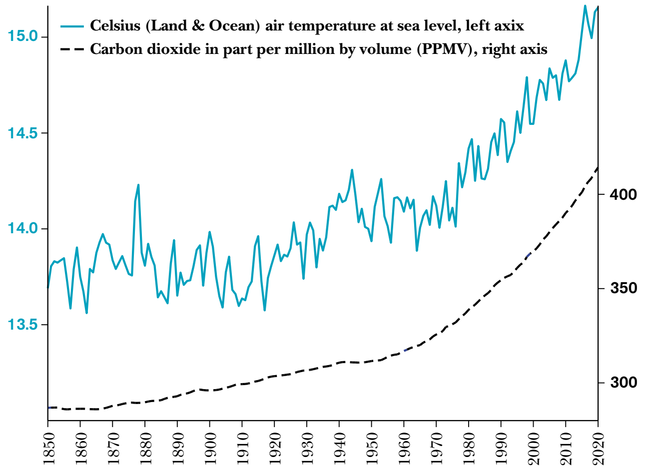

Figure 1: Average global annual temperatures and atmospheric carbon dioxide, 1850-2020

Figure 1 also illustrates the levels of atmospheric carbon dioxide, a major greenhouse gas.[2] Greenhouse gasses work by allowing high-frequency sunlight energy into the troposphere but blocking much of the lower-frequency heat energy from escaping. The scientific consent is that increased temperatures are mainly due to increased greenhouse gasses. Atmospheric carbon dioxide has increased by just over a third since 1850.

Figure 2 illustrates sunlight energy reaching Earth, measured as Total Solar Irradiance (TSI) in kilowatts per square metre (kW/m2). TSI has a short cycle of about 11 years that coincides with planetary alignments. Solar TSI is included in our models but this is unlikely to explain much of the temperature increase because the overall fluctuation in TSI is a relatively small 0.18% with just a 0.0025 kilowatt increase relative to a level of about 1.36 kilowatts. We have overlaid a 'smoothed TSI' variable on the original one that suggests a two-century cycle but this is hard to confirm with less than two centuries of data. We have also illustrated the 'Solar (TSI) cycle' which is the difference between TSI and 'smoothed TSI'.

Figure 3 illustrates data on solar dimming caused by particulates high in the stratosphere. This is known as Stratospheric Aerosol Optical Dimming (SAOD). SAOD data are measured at the 550nm (nanometre) electromagnetic wavelength. Greater dimming leads to cooling by reducing the sunlight reaching Earth's surface. These dimming data have several peaks that coincide with major volcanic eruptions. Eruptions with a Volcanic Explosivity Index of 6 have been illustrated[3] (see https://en.wikipedia.org/wiki/Volcanic_Explosivity_Index for a definition of the VEI.)

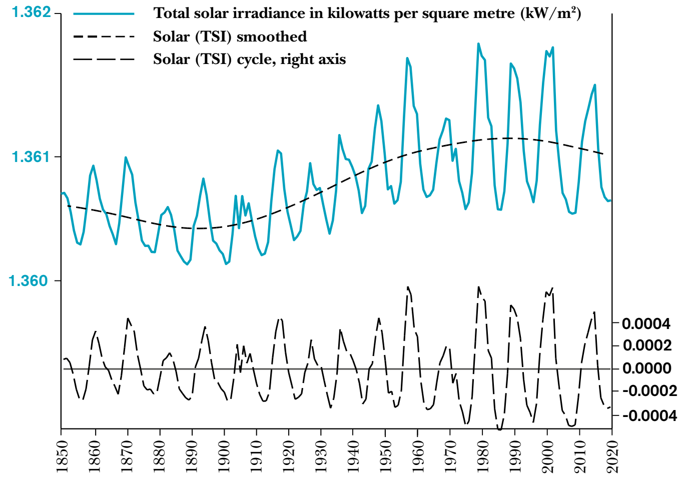

Figure 2: Total Solar Irradiation (TSI) reaching Earth in kilowatts per square metre

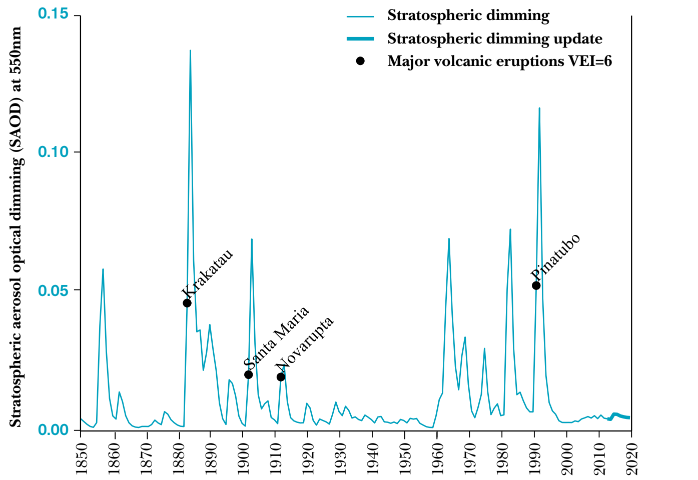

Figure 3: Total Solar Irradiation (TSI) reaching Earth in kilowatts per square metre

2 Foote (1856, American Journal of Arts and Science) is now credited with discovering the Greenhouse Gas effect, based on experimental models using glass cylinders and sunlight. Her work remained largely unacknowledged until it was rediscovered by Sorenson (2011, Search and Discovery).

3 Unfortunately, these data do not go back to the 1815 Tambora eruption (VEI=7). This had a major climatic impact (https://en.wikipedia.org/wiki/Year_Without_a_Summer) and 1816 is sometimes referred to as 'the year without a Summer'.

The statistical model

In this section we will look at the results of fitting two *statistical models* to the data using the *method of least squares*[4]. In particular we use ordinary least squares (OLS), which is the simplest of these methods. OLS involves selecting the model parameters that generate the smallest (squared[5]) difference between the observed temperatures and temperatures fitted by the model. At the end of this section, we will see how to carry out these model estimates using the Excel software.
The first statistical model we fit to our data is on temperatures, carbon dioxide, total solar irradiance (TSI) and stratospheric dimming. The resulting model is:

Celsius = 0.0104 Carbon dioxide + 48.63 Solar (TSI)
– 1.79 Dimming + 0.42 El Niño 1877-1878 – 55.4 + e
(1)

where we have also included a variable for the major El Niño event, set equal to one on 1877 and 1878, and zero elsewhere.

The parameter numbers in model (1) indicate how much each unit of each variable contributed to temperatures. For example, each part per million of carbon dioxide contributes an estimated 0.0104 increase in Celsius temperatures. Since 1850, carbon dioxide has increased by 128.3 parts per million, contributing to an estimated 1.33 (= 0.0104 x 128.3) degrees to the temperature increase. Solar irradiation also makes a positive contribution of 48.63 degrees per kilowatt. Increased Solar irradiance therefore contributed approximately 0.12 (= 48.63 x 0.0025) of a degree to increased temperatures. The upward dimming spikes illustrated in Figure 3 correspond with temperature falls based on the parameter –1.79. The El Niño 1877-1878 event has a large positive effect on temperatures raising them by 0.42 of a degree over this two-year period. The final parameter –55.4 is a constant that captures all that is missing in the model, such as the temperature effects of atmospheric water vapour or atmospheric methane, ozone and nitrous oxide. In a near-complete model we would have expected this constant term to be close to -273.15, which is absolute zero. Given no model is perfect, the residual errors e in model (1) represent differences between the observed and model-fitted temperatures.

Figure 4 illustrates the temperatures already seen in Figure 1, overlaid with the temperature values fitted from model (1). We can see how good the overall fit in this model is. Figure 4 also reports the squares of the residual errors e in model (1) that were minimised to fit the model. These represent the smallest squared residual errors that could be achieved when fitting the model using the method of ordinary least squares.

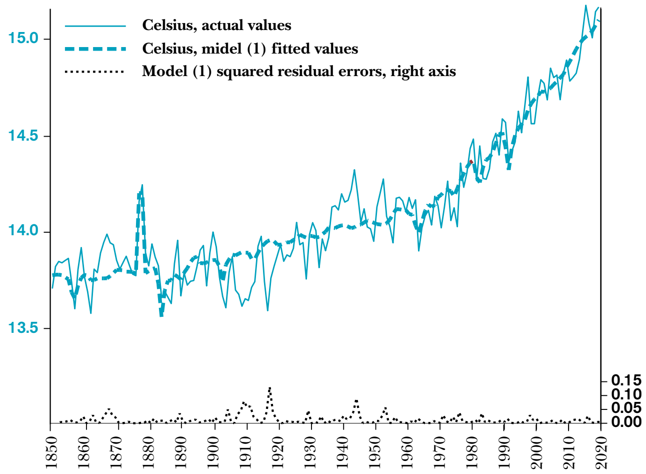

Figure 4: Actual and model (1) fitted Celsius temperatures, and squared residual errors

In our second model we split the Solar (TSI) into its smoothed component and its cyclical component already illustrated in Figure 2. The resulting OLS model is:

Celsius = 0.0098 Carbon dioxide + 161.2 Solar Smooth + 11.31 Solar Cycle
(2) – 1.87 Dimming +0.425 El Niño 1877-1878 – 208.4 + e

Model (2) is very similar to model (1) with carbon dioxide explaining an estimated 1.26 (= 0.0098 x 128.3) degrees of the temperature increase. The main difference is the separate parameters on the two solar activity variables. The parameter on 'Solar Smooth' is 161.2, suggesting a stronger influence than in model (1). Model (2) suggests increased Solar irradiance has contributed approximately 0.40 (=161.2 x 0.0025) of a degree to increased temperatures. The paramete on the 11-year Solar Cycle is much smaller at 11.31, suggesting a very small effect.

How to fit a statistical model using Excel

Models such as (1) and (2) can be estimated using any statistical software (such as R, SPSS or Stata) and can even be carried out using spreadsheet programs such as Excel. Your estimated results are likely to differ very slightly from those in this article because the data are being continually fine-tuned and your dataset might not span the same years. Most people will probably have access to Excel and wish to use it to estimate their models. First make sure that the Excel 'statistical add-ins' are activated by selecting: File, Options, Add-ins, Go; and then make sure the 'Analysis ToolPak' and 'Analysis ToolPak (VBA)' options are ticked. To estimate equation (1) select: Data, Data Analysis, Regression and OK to launch the 'Regression' box illustrated in Figure 5. In the

[4] The method of least squares was first developed by astronomers such as Gauss (1777-1855, https://en.wikipedia.org/wiki/Carl_Friedrich_Gauss) and Legendre (1752-1833, https://en.wikipedia.org/wiki/Adrien-Marie_Legendre) to forecast the trajectory of comets.

[5] The reason for minimising the squares of the residual errors is both a matter of mathematical convenience but also because it confers useful statistical properties in the model. This is something that was discovered by the early astronomers.

"Input Y Range" box insert the column with Celsius. In the "Input X range" box, insert the columns for Carbon dioxide, Dimming and Solar. If you included the variable labels when selecting the data ranges, tick the box for "Labels". Then click OK and this should place a new estimated model into a new worksheet in the same Excel workbook. You can repeat a similar process to estimate model (2) but might need to reposition some data columns to achieve this.

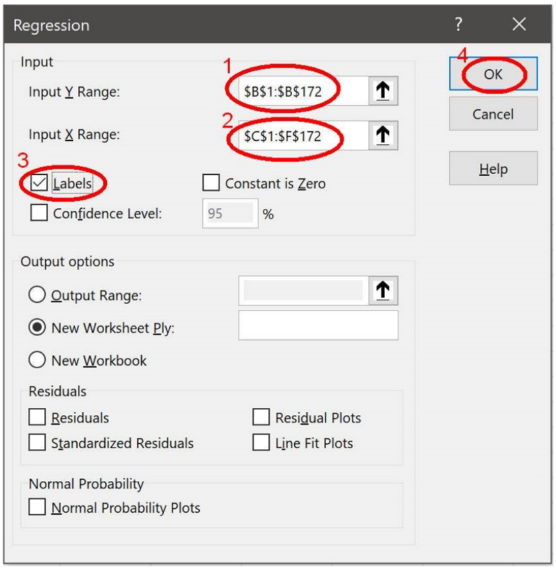

Figure 5: Excel 'Regression' box used to estimate statistical models.

Summary

This article has shown us how to estimate a statistical model of climate change. In the first section we have seen various climate variables and gained an initial insight into how they might be interrelated. In the second section we have seen how to use Ordinary Least Squares model-fitting to estimate two models of climate change. All of the proposed climate variables have some impact on the temperature increase experienced since 1850 but by far the greatest contribution comes from increased atmospheric carbon dioxide. The article appendices touch on data sources some advanced topics when it comes to statistical models of time-series data.

Data sources appendix

Temperature data in Figure 1 are from Berkeley Earth (http://BerkeleyEarth.org) Land and Ocean temperatures at sea level, developed by Rohde and Hausfather (2020, https://doi.org/10.5194/essd-12-3469-2020). Berkley Earth describes itself as "Independent, non-governmental, and open-source" and was originally established to look into the "merit[s] in some of the concerns of climate skeptics".

Post 1959 carbon dioxide data in Figure 1 are based on atmospheric air readings at the Mauna Loa Observatory in Hawaii, made available by the Global Monitoring Laboratory (https://www.esrl.noaa.gov/gmd/). Historical carbon dioxide data are based on numerous polar deep ice-core readings (https://www.ncdc.noaa.gov/data-access/paleoclimatology-data/datasets/ice-core) by MacFarling Meure et al. (2006, https://doi.org/10.1029/2006GL026152).

In Figure 2, recent TSI data spanning 1978-2020 by Coddington et al. (2015, https://doi.org/10.7289/V55B00C1) are based on satellite readings and were retrieved from www.ncdc.noaa.gov/cdr/atmospheric/total-solar-irradiance. Two historical TSI datasets by Marvel et al. (2015, https://doi.org/10.1038/nclimate2888) and Miller et al. (2014, https://doi.org/10.1002/2013MS000266) were retrieved from https://data.giss.nasa.gov/modelforce/solar.irradiance. Where the TSI data overlap, we use an average of the readings.

Figure 3 solar dimming data spanning 1850-2012, with updates to Sato et al. (1993, https://doi.org/10.1029/93JD02553), were retrieved from http://data.giss.nasa.gov/modelforce/strataer/ using the last available dataset tau.line_2012.12.txt. These are constructed from volcanic ejecta, terrestrial readings and satellite readings. We constructed the missing 2013-2020 data by using detailed monthly data on volcanic eruptions retrieved from the Smithsonian Institution Global Volcanism Program using their data retrieval tool: https://volcano.si.edu/search_eruption.cfm and supplemented with data by Siebert et al. (2010, Volcanoes of the World) from www.allcountries.org/ranks/volcano_explocivity_index_ranks.html.

Advanced statistical appendix

In this appendix we touch on some important but advanced issues related to statistical model estimation. The first issue is related to ensuring the estimated models are not spurious regressions and the second issue is to construct valid significance test statistics on the estimated parameters.

The first issue is that it is easy to fit statistical models to data that are non-stationary, such as ever-increasing temperatures. To demonstrate that the statistical model is not a spurious regression we need to demonstrate that its residual errors are mean-reverting. This is typically done using unit root tests of non-stationarity. Applying the most commonly used one of these, the "Augmented" Dickey and Fuller (1981, https://doi.org/10.2307/1912517) (ADF) test to the residual errors of models (1) and (2) produces the following test statistics. These indicate the two models are super-consistent, cointegrated and not spurious because the residual errors are mean-reverting:

ADF test on model (1) residual errors, t-statistic = -7.4455, p-value = 0.000007
ADF test on model (2) residual errors, t-statistic = -7.5684, p-value = 0.000024

The p-values, based on MacKinnon (2010, https://www.econ.queensu.ca/research/working-papers/1227), indicate strong rejection of non-stationarity of the error-residuals.

Dependent variable: Celsius temperatures in Engle-Yoo (1987) models

	Model 1				Model 2			
	(1.i)		(1.iii)		(2.i)		(2.iii)	
Regressors:	Param.	t-stat	Param.	t-stat	Param.	t-stat	Param.	t-stat
Carbon dioxide	0.0104	35.77***	0.0107	15.95***	0.0098	24.43***	0.0093	10.46***
Dimming	-1.790	-4.16***	-4.78	-4.87***	-1.872	-4.38***	-4.831	-5.16***
El Nino 1877-1878	0.420	5.20***	0.970	5.29***	0.425	5.32***	0.956	-5.04***
Solar (TSI)	48.63	1.75	69.30	1.10				
Solar Smooth					161.2	2.76**	329.7	2.59**
Solar Cycle					11.31	0.35	-18.32	-0.26
Constant	-55.40	-1.47	-65.97	-2.05**	-208.4	-2.63**	-298.4	-4.38***
R2	91.5%				91.7%			

Probability of having erroneously included this parameter * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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The second issue is that we typically wish to test whether each model parameter is equal to zero and this is based on standard t-statistics. However standard t-statistics are not valid because some of the variables are non-stationary. Various corrections are possible and we apply the Engle and Yoo (1987, https://doi.org/10.1016/0304-4076(87)90085-6) three-stage estimation correction. The first stage includes the models already reported in models (1) and (2) but the t-statistics are not valid. The second stage (not reported) includes error-correction models with three-year lags of first-differenced temperatures and carbon dioxide among the regressors. The third stage involves adjusting the first stage results based on second-stage correction results. The first-stage (i) and third stage (iii) results for models (1) and (2) are reported in Table 1.

The Table 1 results confirm that most of the variables are statistically significant in explaining global Celsius temperatures. Only the Solar activity variable is not significant in models (1.i) and (1.iii) but this might be because the short 11-year cycles are masking the effect of the long fluctuation. When Solar activity is split into its smoothed fluctuations and its short Solar Cycles, we see that the smoothed component is significant in explaining temperature changes. In all the models, carbon dioxide remains the most significant variable in explaining global warming.

Water security and climate change

Water security is concerned with availability of adequate quantity and quality of water for different uses and users. We need water for domestic (e.g. drinking, cooking, bathing, washing) and non-domestic (e.g. food and electricity production, industry, navigation) uses. Water also maintains and restores natural ecosystems. Some definitions of water security are narrow and focus on human beings exclusively - only individuals or both individuals and communities, the public and the private sector. Other definitions recognise the relationship between human and natural systems and include the natural environment as well. The spatial and temporal dimensions of water (in)security are intricately linked with principles of inter-generational and intra-generational equity. This means, among other things, that water security requires water to be stored e.g., in aquifers, glaciers, and ice sheets to ensure availability not only in the short-term but also the medium- and long-term for people living in different countries and regions within countries, and experiencing different socio-economic and cultural realities, in the present and future generations.

Water insecurity – the converse of water security - will result in conflict between different uses and users of different sources of water at different levels – from the local to the national to the global. This should not be equated with the spectre of 'water wars' between states but it is no less frightening. It is also important to remember that water insecurity is not an issue we might have to contend with in the future; it is the reality right here, right now. Water security is directly related to food security. According to the International Food Policy Research Institute, approximately half of global grain production will be at risk due to water stress by 2050 if business-as-usual persists.

The relationship between climate change and water security

Climate change is likely to exacerbate water insecurity and conflict among different uses and users of water. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) noted that water resources would experience 93 per cent of the impacts of climate change. More recently, the UN World Water Development Report 2020 noted that climate change increases the vulnerability of freshwater resources i.e., any naturally occurring water except seawater and brackish water. The IPCC's Sixth Assessment Report will provide an update on the impact of climate change on water resources.

Rising temperatures, changes in rainfall patterns, and more extreme, less predictable, weather events are likely to lead to adverse effects on water resources in the following ways, among others:

- Boost evaporation
- Snow falls as rain
- Melting of glaciers, ice sheets, snow
- Frequency and magnitude of floods and droughts
- Wildfires
- Availability of surface water and groundwater

Heavy rainfall and breakdown of water treatment infrastructure during floods and extreme weather events can increase sediment and pollution loads in water sources. This will affect the quality of raw water and drinking water.

The IPCC identifies a direct correlation between the increase in concentration of greenhouse gases (GHG) and the adverse impacts of climate change on freshwater resources. Climate change mitigation measures to reduce GHG emissions could promote water security. Alternatively, mitigation measures could exacerbate water insecurity. Water is required to implement climate change mitigation measures e.g., generation of renewable energy (hydropower, geothermal) as an alternative to fossil fuel use and carbon sequestration in sinks through reforestation, bioenergy production and carbon capture and storage.

Climate change adaptation measures could also contribute to water security. Such measures include water retention by forests, wetland, and artificial storage facilities, soil improvement and water management in rain-fed agriculture, and flood protection measures. However, climate change adaptation measures in other sectors such as expansion of irrigation farming may affect the availability, quantity and quality of water resources. Improvements in water management could promote climate resilience without being labelled as climate change adaptation measures. Alternatively, water mismanagement could impede mitigation and adaptation to climate change.

Water (security) in the international climate change regime

The international climate change regime includes the 1992 United Nations Framework Convention on Climate Change (UNFCCC), the 1997 Kyoto Protocol, and the 2015 Paris Agreement. The 2030 Agenda for Sustainable Development's 17 Sustainable Development Goals include a specific one on climate action.

The UNFCCC explicitly acknowledges the relationship between climate change and water. It recognises that low-lying and other small island countries, countries with low-lying coastal, arid and semi-arid areas or areas liable to floods, drought and desertification, and developing countries with fragile mountainous ecosystems are particularly vulnerable to climate change. In fact, all parties accepted a commitment to cooperate to 'develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods.'

Like the UNFCCC, the Paris Agreement recognises that certain countries are particularly vulnerable to the effects of climate change. Unlike the UNFCCC, it does not specify the countries or include any reference to floods, droughts, and desertification. The Paris Agreement does not mention water at all, but water is implicitly embedded in several provisions. The Agreement aims to strengthen the global response to the threat of climate change through mitigation and adaptation measures. Nationally Determined Contributions (NDCs) specify the mitigation and adaptation measures that parties to the Paris Agreement commit to undertake to achieve this objective. 93 per cent of Intended NDCs submitted by countries in 2015 identify water as a central component of their adaptation efforts. Some INDCs link water to the provision of sustainable energy, which is a key climate change mitigation measure e.g., through construction of dams for hydropower generation. Further, the preamble of the Agreement recognises the fundamental priority of safeguarding food security, which is inextricably linked to water security and energy security. The preamble also states that parties to the Agreement should respect, promote, and consider their obligations on human rights. This presents another opportunity to acknowledge the link between climate change and water security, which implicates the right to water as well as the rights to environment and sanitation, and to undertake necessary measures to ensure complementarity between climate change mitigation and adaptation measures and water security at different levels. In any case, the Paris Agreement is intended to enhance the implementation of the UNFCCC, which includes a specific commitment with respect to water. This leaves the door open for consideration of the relationship between climate change and water.

Non-binding outcomes of governmental and non-governmental processes can also influence the international climate change regime. Here we are witnessing greater engagement with the relationship between climate change and water. Even before the Paris Agreement was signed, the Paris Pact on Water and Adaptation – Strengthening Adaptation to Climate Change in the Basins of Rivers, Lakes and Aquifers was entered into at the 21st session of the Conference of Parties of the UNFCCC (COP-21) in Paris in 2015. It represents a commitment to strengthening climate change adaptation through a joint, participative, integrated, and sustainable water resources management. The following year, for the very first time, a dedicated water action day (action day for water) was included in the Global Climate Action Agenda during COP-22 in Marrakech. It called for more attention to water as a way of providing solutions to help implement the Paris Agreement. Water action events have now become an annual feature (2017, 2018, 2019, and 2020).

Another relevant outcome from COP-22 is the Marrakech Partnership for Global Climate Action, which enables collaboration between governments and the key stakeholders such as cities, regions, businesses, and investors. In 2019, the Marrakech Partnership launched Climate Action Pathways to outline the longer-term sectoral visions for a 1.5° climate resilient world in 2050 from the perspective of non-State stakeholders and set out actions needed to achieve that future. The Water Climate Action Pathway seeks to identify and accelerate action on water-related solutions on climate change mitigation and resilience. Other partnerships focus on geographical areas or stakeholders and include the Megacities Alliance for Water and Climate and the Business Alliance for Water and Climate.

Addressing climate change, ensuring water security

The relationship between climate change and water security is complex. As we inch towards COP-26 in Glasgow later this year, any future roadmap to address climate change must consider the following suggestions:

(i) Climate change causes or exacerbates water insecurity by compromising the availability, quantity and quality of different sources of water for human and non-human uses at the global, regional, national, and sub-national levels. The international climate change regime must explicitly consider the relationship between climate change and the hydrological cycle as well as the multi-scalar dimensions of both. At the same time, the regime must be guided by the differentiation principle. Water insecurity and vulnerability to climate change go together for some countries. These countries also fare poorly on the human development index.

(ii) The international climate change regime implicitly recognises the importance of water in achieving mitigation and adaptation goals. This is evident from a perusal of NDCs. However, the discretion vested in the parties to the Paris Agreement as they implement this bottom-up approach could be steered towards ensuring that they consider the reciprocal relationship between climate change mitigation and adaptation measures on one hand, and water resources and water security on the other.

(iii) Climate change adaptation measures might protect water resources explicitly and promote water security implicitly. However, the international climate change regime adopts an exclusive or predominantly climate lens. The fact that several mitigation and adaptation measures require water as an input might amplify the threat of water insecurity for individuals and communities receives less attention. We need a more nuanced approach that recognises that solutions to one problem might create another problem. Climate change mitigation and adaptation measures might result in water insecurity.

(iv) Climate change mitigation and adaptation measures do not always operate in isolation from one another. Complementarities are welcome but we cannot rule out the potential for water resource conflicts between adaptation and mitigation with implications for water security at different scales and during different time-periods. To the extent possible, a simultaneous evaluation of these measures is necessary while recognising that there is no hierarchy between the two.

(v) The international climate change regime must facilitate the engagement of civil society organisations in discussions on climate change and water. It must also expand the pool of stakeholders to ensure that voices of concerned individuals and communities and of experts (scientists) from different countries are heard and included in the decision-making processes.

(vi) Decision-makers must recognise and explore the synergies between the international climate change regime and international law relating to biodiversity, human rights, watercourses, and wetlands, among others. They must also acknowledge and fill gaps in international law e.g., concerning aquifers and polar ice that impede the development and operationalization of a comprehensive approach to address climate change while ensuring water security.

Lovleen Bhullar

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Berta Bonet, Iseult Lynch and Stefan Krause

Freshwater biofilms as early warning systems for the combined impacts of climate change

and particle pollution (microplastics, engineered nanomaterials, pathogens) on water quality

New research in our artificial stream mesocosms has shown that the increased temperatures predicted to occur by mid-century will lead to reduced aquatic biofilm diversity and enhanced susceptibility to other stressors. We found that combined exposure to elevated temperature and silver nanoparticles led to increased cell death in the biofilms of our artificial streams and a reduction of the surrounding protective matrix, as well as enhancing the toxicity of silver sulfide nanoparticles currently considered to be of low risk. As biofilms contribute to essential ecosystems services, such as water quality and nutrient recycling, monitoring of UK waters under the UK 25-year Environment plan and the River Basin Plans should include and prioritise biofilm health, and strategies to utilise biofilms for monitoring and remediation since there is a strong connection between healthy ecosystems and human health.

While for most of us, biofilms are the undesirable green/brown slime that cover buildings, boats, rocks and other surfaces in frequent contact with water, in their natural habitat, freshwater biofilms are an extremely hardworking part of the ecosystem, providing a range of essential services (often called ecosystems services) including water purification, carbon storage and nutrient cycling. Biofilms colonize any wet or submerged surface (substrate), and indeed recent advances in techniques for assessing microbial composition have shown that biofilms lining the pipes that bring drinking water into our homes may contribute to the high quality of drinking water, acting like the "good bacteria" in our guts by filtering out pollutants. Surface colonisation of biofilms is driven by extracellular polymeric substances (EPS) secreted by the bacteria, and this sticky mucus provides biofilms with stability and community structure, making them more resilient to pollution than individual microbes.

Berta Bonet, Iseult Lynch and Stefan Krause

Freshwater biofilms as early warning systems for the combined impacts of climate change and particle pollution (microplastics, engineered nanomaterials, pathogens) on water quality

Biofilms are hugely variable in their composition, comprising algae, bacteria, and fungi, embedded in a protective mucus matrix (Figure 1), with each of the species having different functions and abilities. An established biofilm has a defined architecture, and biofilm-associated organisms differ from their planktonic (freely suspended) counterparts with respect to the genes that are expressed. Freshwater biofilms can also incorporate clay materials, suspended solids, and corrosion particles entrapped into their mucus matrix, and are well-known as sinks for pollutants (Bonet et al., 2012, 2014) thus aiding water purification. The different species within biofilms are closely associated and interact strongly with each other through secretion of signalling molecules (so-called quorum sensing). These interactions can be cooperative or competitive and are strongly affected by surrounding conditions; biofilms composition and structure change as they are exposed to extremes of flow, temperatures, light and nutrients in rivers and ponds.

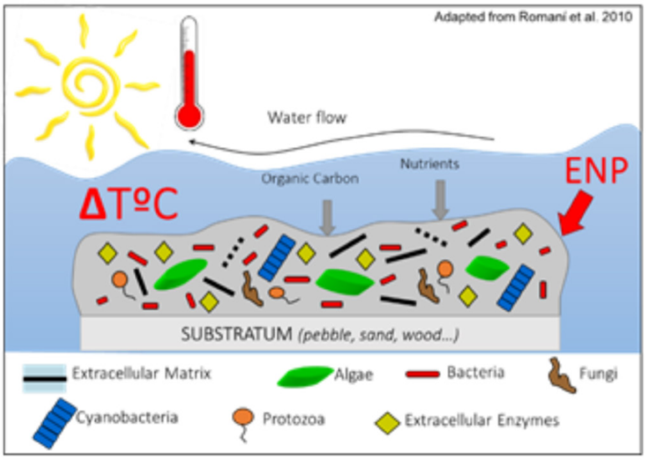

Figure 1: Schematic illustration of the impacts of increasing temperature (T) and interaction with engineered nanoparticles (ENP) in terms of their composition, structure, and function.

Aquatic ecosystems are threatened by multiple environmental stressors including pollutants and climate change. Climate models predict mean annual temperature to increase by 3.5°C in air and 2.2–4.3°C in stream waters by 2100, and increased frequency of extreme hydrological conditions including droughts and floods, with potentially devastating effects on freshwater ecosystems and their ecosystem services. These predictions are reinforced by the UK Climate Projections 2018 study, the most up to date assessment of how the UK may change over this century, which also suggests that under the highest emissions scenario, summer temperatures could be 5.4ºC hotter by 2070, with the chances of a summer as warm as 2018 (when daytime temperatures in parts of the country consistently topped 30ºC are around 50% by 2050. Even under a low emissions scenario, the Met Office data indicate that the UK will see an increase in the average yearly temperature of up to 2.3ºC by 2100. In freshwater systems, both temperature and hydrology are key controls on the rates of vital physiological processes such as respiration, growth, metabolism and enzymatic activities, and even small (e.g. 2ºC) shifts in temperature could markedly alter biofilm structure and functioning, and streams desiccation or drying out would alter the nutrient cycle (as biofilms become more heterotrophic i.e., needing to get nutrients by eating other organisms) and bacteria use more carbon and phosphorus for growth rather than nitrogen).

While considerable progress has been made in understanding the environmental impact of many stressors in recent years, new potentially powerful, toxicants such as engineered nanoparticles (ENPs) and microplastics arising from mis-managed plastic waste, continue to emerge whose effects on aquatic ecosystems remain poorly understood. The release of ENPs into the environment is accelerating due to their widespread applications in cosmetics, textiles, food packaging, building materials, electronics and more. Current regulatory testing utilises standardised over-simplified conditions, and does not factor in any enhanced organism susceptibility due to climate change or other stressors. The impact of combined climate change and particle impacts on individual species, for communities such as river biofilms, and for the essential ecosystems services they provide are critical questions that require answers. European environmental legislation such as the Water Framework Directive (WFD 2000/60/EC) recognises the need to manage the environmental threat posed by climate change coupled with contamination, but knowledge of new ENP and microplastics stressor effects is only beginning to emerge.

As a major step towards understanding the climate change-enhanced environmental impacts of ENPs in aquatic ecosystems, the Horizon 2020 funded project NanoTOX elucidated how much river warming affects fluvial biofilms structure and function, and how the presence of environmentally relevant concentrations of representative ENPs may further stress the communities (Figure 1). This was achieved through an innovative, interdisciplinary approach using an array of methods from the fields of ecotoxicology (ecology and toxicology), molecular biology, functional ecology and nanotechnology. Utilising UoB's Environmental Change Outdoor Laboratory (or ECOLaboratory) and its recirculating streams at different temperatures, flows and pollution conditions, a large-scale mesocosms experiment was performed exposing biofilms to low concentration of ENPs at current and expected temperatures (18ºC vs. 25ºC). Since there is ongoing debate as to the role of nanoparticles versus dissolved ions, and the impacts of newly released (freshly dispersed) versus environmentally aged (transformed) nanoparticles, our experimental design included pristine silver nanoparticles (AgNP), silver ions as an ionic control (AgNO3) and a silver sulfide nanoparticle (Ag2S NP) designed to mimic the transformation that AgNPs undergo in the environment, such as during transport through wastewater treatment plants which are high in sulfide and a key route into the environment for nanoparticles.

The experiment involved 40 flumes of 60 Litres each, 20 set at 18 °C and 20 set at 24 °C, with 4 different pollutant treatments each: (i) untreated control, (ii) silver ENPs (AgNP, pristine ENP), (iii) silver sulphide ENP (Ag2SNP, aged ENP) and (iv) silver nitrate (AgNO3, ionic control Ag+), as shown in Figure 2. To assess differences over time, water and biofilm samples were collected just before adding the toxicants (0h) and after 1 and 3 days to assess acute effects, and after 14 and 30 days to assess chronic effects. Functional and structural analyses were performed according to the protocols developed within the project.

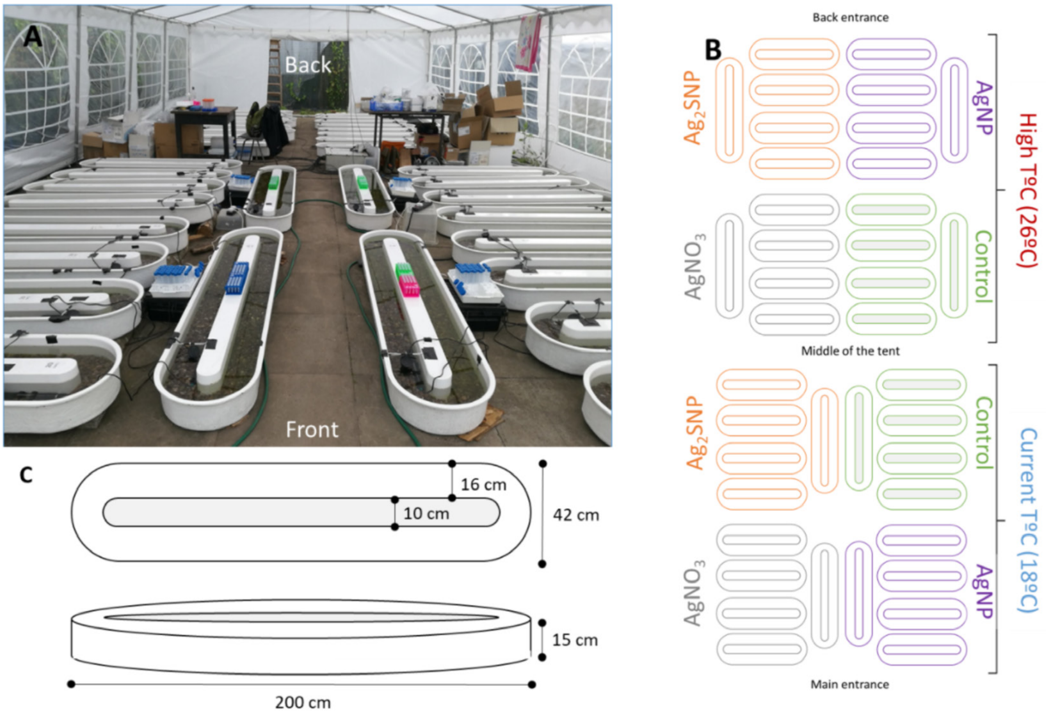

Figure 2. (A) a photo of a former ECOLaboratory and (B) a scheme of the mesocosms set-up used to perform the experiment. (C) Detail of flume dimensions.

Project results highlight that a temperature increase of 6 °C enhanced algal biomass, photosynthetic activity, and some enzyme activities while others decreased. Microscopic images showed a homogenisation of biofilm community composition (see Figure 3). These shifts should be taken seriously by river managers since they can modify the nutrient cycle in the freshwater systems as well as other ecosystem services, such their involvement in the global carbon budget, and thus have an important effect on the quality of water not only for the organisms who are living in the systems but also for human health. Both pristine and aged ENP agglomerated as soon as they were released into the system, due the content of divalent cations in water (calcium and magnesium). Even with such agglomeration, that could reduce the potential toxicity of AgENP, different toxic effects were observed between the different forms. AgNPs caused negative effects on fluvial biofilm respiration and on all diatom forms at 18 °C. Despite the effect on diatoms, AgNP biofilms retained or increased overall algal biomass and photosynthetic activity. Extracellular enzyme activity in biofilms (Phosphatase) was clearly affected over time by the Ag2S ENP and AgNO3 but not by Ag ENP. Phosphatase activity (related to phosphate degradation) was affected by aged ENP (Ag2SNP). These results are important since in theory these aged and unreactive ENP "should not cause" any biological effects and are considered to be of low toxicity. Increased temperature also affects ENPs properties such as solubility, dissolution and toxicity (Reidy et al, 2013), while flooding can (re-)mobilise the particles or enhance their sedimentation under drought conditions (as happens with natural particles). These results have important implications for the spreading of wastewater treatment plant sludge on agricultural soils, since aged ENP (Ag2S NP) in theory "should not cause" any biological effects and are considered to be of low toxicity. Increased temperature also affects ENPs properties such as solubility, dissolution and toxicity (Reidy et al, 2013), while flooding can (re-)mobilise the particles or enhance their sedimentation under drought conditions (as happens with natural particles). These results have important implications for the spreading of wastewater treatment plant sludge on agricultural soils, since aged ENP (Ag2S NP) in theory "should not cause" any biological effects, but under climate warming conditions had effects on fluvial biofilms and thus might also affect soil microbial communities and thus soil health and productivity.

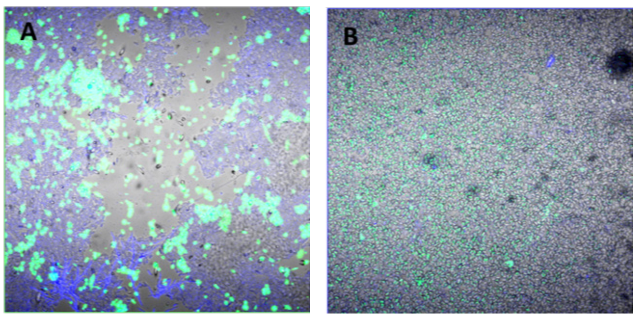

Figure 3. (A) Biofilm after 4 weeks at 18°C and (B) at 25°C, without any nanomaterials. Images show biofilm homogenisation at higher temperature and loss of extracellular polymeric substances.

Micro and nanoscale plastic particles have many features in common with ENP, including their particulate nature. The effect of temperature on microplastics' physical properties (e.g., increasing density causing faster sedimentation) and surface properties (e.g., making them less hydrophobic), coupled with the aforementioned impacts of temperature on aquatic biofilms behaviour can affect the leaching rates of additives and plasticizers from microplastics. Thus, microplastics and their components will affect microbial communities and their ecosystem services, while the biofilms will alter the microplastics' properties. There is thus a critical risk that global warming effects will markedly exacerbate the toxic effects of microplastics on fluvial biofilms, impacting on their function and provision of essential ecosystems services. Additionally, the role of biofilms in sequestering microplastics could be utilised as a low-cost strategy for their removal from water. Moreover, if specific plastics are found to age more effectively, or if biofilms are found to be effective barriers, this could be utilised more widely as a low-cost wastewater treatment strategy. Indeed, the first reports of utilising biofilms to trap microplastics for remediation, and of combining microbial biofilms and phytoremoediation via floating rafts, are beginning to appear in the literature, although again have not been assessed for their robustness under elevate climate conditions.

Our research is also exploring the impacts and opportunities presented by freshwater biofilms to act as indicators and mitigators of the ecosystems impacts of combined threats of particulate pollution and climate change. This knowledge will support policy makers involved in river restoration, waste management, environmental remediation and more, and will feed into the 25-year Environment plan. Indeed, it is striking that Data figures released by the Environment Agency showed that no UK river has achieved good chemical status, suggesting pollution from sewage discharge, chemicals and agriculture are having a huge impact on river quality, based on the more stringent test standards compared to those used in 2016 when 97% of rivers were judged to have good chemical status. Our data on the combined impacts of particulate pollution and climate change on fluvial biofilm structure and function indicate an urgent need to review freshwater monitoring guidelines - it is extremely important to not only monitor water physicochemistry to assess and manage freshwater systems (risk assessments), but also to include biological analyses of ecosystem functioning, which are crucial in order to understand if a system is polluted and how it is affected. Biofilm is a powerful bioindicator of ecosystem health and can detect the bioaccumulation of metals (and most likely also plastics or their additives) even when levels are under the detection limit in water. The forthcoming changes to the UK river monitoring network planned as part of the River Basin Management plans 2021, as well as the improving quality of using fluorescence-based water sensors enable the detection of metabolism of biofilms *in-situ*. Complementing these, our current research is focussing on developing in-situ analysis tool to detect microplastics in situ in river systems (e.g. our team are currently developing a low-cost field-deployable Raman system for microplastic quantification in rivers via the Institute for Global Innovation theme on "Water Challenges in a changing world") offer exciting new opportunities for UK-wide monitoring of biofilm health and interactions with microplastics, to support a range of regulatory and policy visions including the circular economy and the efforts to improve river health.

This interdisciplinary project is a major first step in opening a new research line in climate-ecotoxicology, focussing specifically on biofilms as entry points to the food web and assessing ENP and microplastics impacts under current and future climate scenarios. Acting now, to monitor combined effects, and determine approaches to mitigate combined stressor effects on our critical river ecosystems is essential, and the solutions developed here are deployable in global south contexts also to support the achievement of Sustainable development goal 6 in providing clean water for all.

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Why the archaeology of peatlands matters as we look to COP26

Peat and peatlands have received considerable coverage in the media in recent months and remain in focus due to the positive contributions they make to climate change challenges at the heart of COP26.

In the UK, new support has been provided for peatland restoration, including the announcement in April of Natural England's 'Nature for Climate Peatland Grant Scheme'. The following month saw the publication of the England Peat Action Plan (EPAP) which included measures including phasing out the sale of peat compost.

With these new initiatives, there is a welcome emphasis on the valuable heritage that peatlands present. Heritage was highlighted within the EPAP, which also draws on the recent publication of Historic England's 'Peatlands and the Historic Environment' paper, focusing on the cultural and heritage value of peat.

But why is heritage so fundamental to peatlands?

Peatlands encapsulate millennia of landscape change, coupled with human adaptation, from populations that lived and foraged within these environments to the final stages of industrial heritage associated with processes of peat extraction.

However, their key importance lies in the detail of the stories they can tell, and this results from their unparalleled potential for preserving organic materials – from wood and leather to perfectly preserved remains of the bodies of animals and even people – that, in most other contexts, would rot away and be lost.

The principal factors that decay organic material are fungi and certain types of aerobic bacteria. In a saturated and stagnant peatland, the impacts of these perpetrators of decay are diminished. Long-term preservation is achieved through stasis - a lack of change within their saturated burial environment.

The remains of preserved structures such as trackways not only inform about past human activity in an area, but also about changes in woodworking and carpentry techniques. From the wood itself, we can learn about past choices of different species for different tasks, and about the woodland management techniques used to procure it, such as the use of 35-50-year-old, overgrown oak coppice in the construction of a causeway on the Waveney in Suffolk. Furthermore, the differential growth of the tree rings in this wood tells us that the whole building enterprise took place within a three-month period – the spring of 75 BCE. Just this example shows how communities over 2000 years ago worked to ensure the future for future generations. Within the context of COP26, this is ever more relevant.

But peatlands do not just preserve the objects and structures that people made in the past. The peat itself forms an archive of past environments. By analysing the macroscopic and microscopic plant and animal remains we can construct detailed understanding of past environmental changed, human response to such change and, in some instances, human impact on their environments. An example from Derryville bog in central Ireland showed how the construction, use and repair of a road through what was a developing bog in the Bronze Age impeded the bog's hydrology resulting in a catastrophic bog burst. A salutary story of human agency creating environmental damage nearly 3,500 years ago.

Although rare, perhaps the most tangible of all archaeological discoveries from peatlands has been the perfectly preserved remains of humans. These examples, known as bog bodies, offer an unparalleled opportunity to be literally face-to-face with our prehistoric ancestors. Most bodies were discovered in times and places where peat cutting was undertaken by hand, although more recent, sometimes very fragmented, remains have been made following mechanised peat cutting.

A perfectly preserved body can tell us so more than just the miracle of being able to see a prehistoric face. Soft tissue and hair, alongside evidence of disease and healed injuries, tell us about who these individuals were in life. Textiles and clothes, where they were buried (for many bodies were placed naked), inform us about their status, but also about how such objects were manufactured. For many bodies, unhealed wounds tell us how they died, in some instances raising questions about the likelihood of ceremonial killing, or rituals of human sacrifice. Their stomachs contain the remains of their final meal, not only giving indications about their economies, but also about the final hours of these individuals' lives.

With such exceptional preservation potential in peatlands, it is perhaps not surprising that our understanding of ancient peoples - of where we come from - builds from the intricate detail that peat presents us with. We hopefully look to a future of reduced peat loss with plans for restoration, with benefits that are paralleled in issues of biodiversity and climate change. But there is still a need for care and caution. Locally, challenges of peat loss through developments persist, with the potential for devastating impacts. And even where we seek to re-wet and restore peatlands, the processes are far from easy, with far reaching implications for heritage. For much archaeology, the impact of the damage is already felt and, unless we act quickly, more will be lost. Re-flooding requires infrastructural manipulation and, once a peatland becomes wet again, the chances to find new sites is severely diminished. Even where sites are found, they become logistically challenging to deal with.

These challenges can be addressed through multi-agency and multi-interest collaboration. To do this, we need to ensure a wider public understanding of the heritage value of peatlands. Recently, such collaboration can be seen in places such as Hatfield Moors in South Yorkshire. Here, within a landscape actively being restored, access and understanding of heritage has been through community ventures and reconstruction projects, the first of which focused on an internationally important Neolithic site towards the centre of the bog. Whilst the site itself cannot be seen on the ground due to the needs for its continued preservation, it can now be experienced through the co-produced replica.

Collaboration on projects such as this provides a framework for engagement and discussion around how the different priorities relating to peatland can pull together. Whether your starting point is climate change, biodiversity, or heritage, their interrelatedness is fundamentally important.

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Energy transition

03

Energy subsidy reform: the fossil elephant in the COP room

Fossil fuel subsidies are major obstacles to the climate change and energy security-driven transition towards sustainable energy sources. They undermine the competitiveness of renewables and encourage the over-extraction and wasteful consumption of energy sources that are responsible for around two-thirds of global greenhouse gas emissions. The increased recognition of their adverse environmental effects over the last few decades has prompted numerous intergovernmental fossil fuel subsidy reform initiatives. However, the primary intergovernmental forum for negotiating the global response to climate change (i.e., the UNFCCC) is conspicuously absent from the forefront of these initiatives. Fossil fuel subsidy reform first appeared on its agenda some three decades ago, but it has remained a peripheral issue within the UNFCCC ever since.

The environmental case against fossil fuel subsidies

The environmental case for fossil fuel subsidy reform is straightforward. Subsidies make fossil fuels artificially cheaper to consume and profitable to produce. Cheap fuel prices encourage wasteful consumption and undermine the pursuit of energy efficiency. Production subsidies in the form of tax emptions and low royalty payments enable the production of fossil fuels that are otherwise economically unviable.

The fact that no other human activity generates more emissions than fossil fuel production and consumption makes the transition away from fossil fuels essential to keep the global average temperature increase below the 1.5°C limit set in the Paris Agreement. However, our current over-reliance on fossil fuels for virtually everything makes the transition one of the most difficult challenges the world has ever faced. Making the transition happen without disruption and delay requires a massive and urgent improvement in the development and deployment of energy efficiency and renewable energy technologies. Countries are taking a wide range of legal and policy measures towards this direction, but their simultaneous subsidisation of fossil fuels is detrimental to the transition.

Renewable energy sources have come a long way in their competitiveness, but they are not likely to outcompete and replace fossil fuels if governments continue to subsidise them. Fossil fuels have benefited not only from decades of subsidies and free public infrastructure but also from the failure of the market to internalise the negative externalities of fossil fuel combustion and the positive externalities of renewables. Switching subsidies from fossil fuels to renewables must be a first-order priority in any country's effort to help accelerate the transition. The COP has already agreed in the Paris Agreement to such action by undertaking to make 'finance flows consistent with a pathway towards low greenhouse gas emissions and climate resilient development'. Fossil fuel subsidies make finance flow in the wrong direction and lock the world into unsustainable and high carbon energy systems.

Intergovernmental fossil fuel subsidy reform initiatives

Fossil fuel subsidies first appeared on the international environmental agenda during the Kyoto Protocol negotiations in the 1990s. An earlier draft of the Kyoto Protocol contained an explicit reference to the progressive phasing out of 'subsidies in all fossil fuels' as one of the policy measures to reduce greenhouse gas emissions. The corresponding provision in the final text of the Kyoto Protocol replaced the specific reference to fossil fuels with a generic reference to subsidies in 'all greenhouse gas emitting sectors'. The diluted language and advisory nature of the provision undermined its ability to attract much attention to fossil fuel subsidies.

Intergovernmental efforts to promote fossil fuel subsidy reform started in earnest with the 2009 G20 Summit at which G20 Leaders agreed to 'phase out and rationalize' 'inefficient fossil fuel subsidies' over the medium term. This agreement has prompted numerous intergovernmental organisations and forums to launch their own fossil fuel subsidy reform initiatives. The Leaders of the Asia Pacific Economic Cooperation (APEC) echoed the G20 commitment to 'phase out inefficient fossil fuel subsidies that encourage wasteful consumption' at their Summit in 2011. The G7 Leaders also agreed to eliminate inefficient fossil fuel subsidies by 2025 at their 2016 Summit in Ise-Shima, Japan. Nine non-G20 countries have formed the Friends of Fossil Fuel Subsidy Reform (FFSR) to advocate for fossil fuel subsidy reforms in various intergovernmental forums. Fossil fuel subsidy reform has also become part of the UN Sustainable Development Goals (SDGs). One of the targets to ensure sustainable consumption and production patterns (G12) is the rationalisation of inefficient fossil fuel subsidies that encourage wasteful consumption by 2030. A group of 12 World Trade Organization (WTO) Members issued a Statement at the last WTO Ministerial Conference in 2017 calling for fossil fuel subsidy reform in the multilateral trading system. Moreover, most recently, five WTO Members have launched negotiations for a plurilateral Agreement on Climate Change, Trade, and Sustainability (ACCTS) that aim, among others, to discipline environmentally harmful fossil fuel subsidies.

These initiatives have successfully made fossil fuel subsidy reform an important component of the climate policy toolkit, but fossil fuel subsidies remain prevalent and considerably higher than renewable energy subsidies. The OECD and IEA estimated that fossil fuel subsidies in 77 economies alone amounted to $478 billion in 2019. This figure is without considering the value of the negative externalities from fossil fuel production and consumption that the IMF counts as part of its post-tax subsidy estimate. Governments are not only failing to phase out their existing subsidy programmes, but they are also introducing new ones. Promising to build back better and greener and at the same time subsidising fossil fuels is affront to such promises – let alone to the various commitments they undertook to eliminate such subsidies.

The UNFCCC and fossil fuel subsidy reform

The Paris Agreement makes no explicit reference to fossil fuel subsidies nor fossil fuels. The reference to fossil fuel subsidy reform as one of the climate finance options in the draft text did not make it to the final text of the Agreement. However, the bottom-up nature of the Agreement affords countries the opportunity not only to determine their own emission reduction targets but also to pick the policy measures to meet them. A few developing countries took advantage of this opportunity to include fossil fuel subsidy reform to their intended climate policy measures. This is a significant step in the right direction but insufficient for at least three reasons. First, only 13 of the 191 Parties to the Paris Agreement mentioned fossil fuel subsidies in their Nationally Determined Continuations (NDCs). This is despite the fact that nearly all countries subsidise fossil fuels in one form or another. Second, with a few exceptions, most of the 13 references to fossil fuel subsidy reform are coached in a broad and imprecise language that is difficult to monitor and ascertain compliance. Third, and most importantly, the mere inclusion of fossil fuel subsidy reform in NDCs falls short of providing the necessary incentive and support governments need to implement such reforms. Governments – especially in the Global South – often face backlash in their attempt to reform fossil fuel subsidies. A recent study found that 41 countries encountered at least one fuel riot between 2005 and 2018 in response to fossil fuel subsidy reforms. Such protests are the function of multiple factors.

The most prominent of this is lack of public awareness and participation of stakeholders in the reform process. Fossil fuel consumption subsidies are often justified in the name of the poor and vulnerable groups of the society. As such, they form part of social welfare policies to protect such groups against high fuel prices. The problem is that most fossil fuel subsidy programmes are targeted so poorly that they benefit middle and high-income households more than low-income households. The regressive nature of most fossil fuel subsidy programmes means that those with higher energy consumption capture most of the benefits. To make matters worse, low-income households are more likely to feel the increased fuel prices in the aftermath of subsidy reforms than their richer counterparts are. Unless fossil fuel subsidy reforms are accompanied by effective public awareness campaigns and more targeted compensatory schemes, they will continue to trigger public protests.

Undertaking fossil fuel subsidy reforms in times of low oil prices such as the current one will also help lessen the backlash. The public backlash also stems from the failure of reforms to encompass compensatory schemes that alleviate the adverse effects of fossil fuel subsidy reforms on low-income households. It is important to acknowledge that low-income households suffer the most from the removal of fossil fuel consumption subsidies. Successful reforms require clear implementation plans and compensatory measures directly targeted at the poor and other vulnerable groups. Countries such as India and Iran have replaced some of their price-based fuel subsidies with direct cash transfers. The implementation of such schemes, however, poses significant administrative burden for most developing countries with weak institutional and human resources. This is one area where international organisations could support fossil fuel subsidy reforms in developing countries.

The reluctance to address fossil fuel subsidies within the UNFCCC (beyond NDCs) stems from the consideration that energy issues remain the exclusive prerogatives of national governments. The numerous multilateral initiatives to promote fossil fuel subsidy reform however suggest that a common understanding and some degree of consensus has emerged on the need to address fossil fuel subsidies at the intergovernmental level. The increasing evidence of the crucial role subsidies play in perpetuating the status quo and maintaining the dominance of fossil fuels in the global energy supply mix is yet another reason why the COP can no longer afford to treat fossil fuel subsidy reform as a peripheral issue. The key item on the COP26 agenda is securing global net-zero by 2050. No pathway to net-zero exists that does not require the fundamental restructuring of the global energy system. Even the International Energy Agency (IEA) has now recognised that a 'radical transformation of the global energy system' is required to achieve net-zero carbon emissions by 2050. The world stands no chance of reaching net-zero and limiting the rise in global temperatures to 1.5 °C without keeping the majority of fossil fuels in the ground. This means that our chance of reaching net-zero carbon emissions by 2050 hinges on our ability to accelerate the transition towards sustainable energy sources. Any net-zero commitment at COP26 therefore needs to come with clear and strong dedication to address one of the major culprits to the energy transition – fossil fuel subsidies.

COP26, Biden and the United Kingdom

COP26 comes at a critical time. The coronavirus pandemic has shown how much the world is ill-prepared to respond to a public health emergency - let alone to the 'even deeper emergency' of climate change. Urgent and co-ordinated action is needed if the world is to stand any chance of avoiding the catastrophic consequences of climate change. Making such action an integral part of the recovery from the pandemic is essential to avoid (and correct) past mistakes and accelerate the transition towards sustainable energy future. Subsidising the fossil fuel industry in the name of recovery will perpetuate and further entrench fossil fuel use. It is therefore imperative that COP26 sends a clear and strong signal on the need to phase out existing fossil fuel subsidies and refrain from introducing new ones under the guise of recovery.

Recent developments in the United States and United Kingdom provide some grounds for optimism on this front. The coming into power of the Biden-Harris administration in the United States and its strong determination to combat climate change will help recover the fossil fuel subsidy reform momentum undermined by the administration of Donald Trump and its pro-fossil fuel and anti-environmental rhetoric over the last four years. The administration has already brought back the United States to the UNFCCC and promised to restore US leadership to global climate action. It has also enjoined Federal Agencies to ensure that 'Federal funding is not directly subsidizing fossil fuels' and 'eliminate fossil fuel subsidies from the budget request for Fiscal Year 2022 and thereafter'. Only time will tell how much of this will translate into action but having one of the leading greenhouse gas emitters and fossil fuel subsidisers on board is crucial for the intergovernmental movement against fossil fuel subsidies. The United Kingdom is also taking important steps in the right direction ahead of COP26. Over the last two years, the government has launched various renewable energy support programmes to help businesses build back greener, promote green innovation and supercharge green start-ups. It has also announced its plans to end support for overseas fossil fuel projects. These measures are crucial to help accelerate the sustainable energy transition, but the continued subsidisation of fossil fuels undermines their effectiveness. It is incoherent to introduce renewable energy support measures and subsidise fossil fuel at the same. The UK is one of the key G20 countries that not only failed to honour their fossil fuel subsidy reform commitments but also introduced new subsidy programmes since the 2009 G20 Summit in Pittsburgh. The government deny its subsidisation of fossil fuels despites numerous reports to the contrary. The government need to stop hiding behind technicalities and a narrow definition of fossil fuel subsidies to maintain policy measures inconsistent with its climate change agenda. The UK has joined forces with the FFFSR recently in calling for fossil fuel subsidy reform at the COP26. The joint communique urges countries to turn their commitments into action with urgency. If the government is serious about tackling climate change and climate leadership, the starting place is to be transparent about its own subsidisation of fossil fuels. Recognition and clear plan of action to reform fossil fuel subsidies is essential for the UK to have any moral authority to urge its guests to take action against their fossil fuel subsidies at the COP26.

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Reducing global temperatures through decarbonisation of heat

In the venture to decarbonise all parts of human activity much of the focus has fallen on energy. Often electricity has been a euphemism for energy and decarbonisation of energy has become the decarbonisation of electricity.

In a UK context great progress has been made. In 2020 42% of the country's electricity generation was from renewable generation rising from 5% over a ten-year period. Coal-based electricity generation has dropped dramatically. In 2010 fossil fuel derived electricity was about three-quarters of generation, now low-carbon sources, including nuclear exceed those of fossil fuels. This is quite a transformation and has been driven by ambitious government policy, enshrined in the 2008 Climate Change Act. The introduction of novel market mechanisms such as contracts for difference (CFDs) and agreed strike prices gave long-term confidence to developers which has seen an extraordinary investment in offshore wind and nuclear projects. The scale of the offshore wind programme has seen the strike price for offshore wind reduce by a factor of 3 to ~£50/MWh. The same level of cost reduction has not been seen in the nuclear sector where only the Hinkley Point C project has made it off the starting blocks. The UK's programme of small modular reactors (SMRs) could unlock a cost reduction pathway.

In the present mix of energy utilisation in the UK, heating accounts for about 40% of the energy consumption and about one third of the carbon emissions. To date, in contrast to electricity, very little progress has been made in the decarbonisation of both domestic and industrial heating. The UK generates most of its heat utilising natural gas and sits at the high end of the spectrum in terms of the carbon intensity. Scandinavian countries, in contrast, are some of the greenest where there are significant components of heating delivered by electricity and district heating.The district heating systems are well-developed pieces of infrastructure which take advantage of waste heat sources such as energy from waste. Little progress has been made in the UK on heat decarbonisation because of the significant challenges involved. Unlike greening of the electricity grid, where the appliances in the home are immune to changes in the source of generation and the switch from coal to wind can be done without any need for the customer to change behaviour, heat will need a change in 25 million homes.

There are three accepted ways of delivering low carbon heating. The approach that UK government has most enthusiastically endorsed is use heat pumps which use electricity to extract heat from the external environment, air or ground, and pump it into the building. The UK government's 10 point action plan for the delivery of net zero sets out an ambition to install 600,000 heat pumps a year by 2028. The challenge with a heat pump solution is that it that it is expensive compared to a gas boiler, by a factor of 10 to 20, and is not a direct one-for-one replacement. The intensity of heat generated by a heat pump is less than that of a gas boiler and hence there is need for hand-in-hand improvements to the thermal efficiency of the home. The cost and level of disruption is therefore high. Alternatives to this approach are either the use of hydrogen or district heating.

In the case of hydrogen the approach is intuitively simple, the natural methane gas in the gas grid is replaced by hydrogen. The gas boilers can either be adapted or replaced by dedicated hydrogen boilers and cooking can also use hydrogen. The challenges to delivering a hydrogen-based solution, however, are not trivial – despite the apparent simplicity. First there is a need to ensure the piping infrastructure used to transport hydrogen is sufficiently modern that the hydrogen does not attack the piping material and cause embrittlement and cracking. Then there is the need to generate sufficient hydrogen at the scale which is required to displace the present methane usage, recognising that the energy density of hydrogen is lower than natural gas. The preferred method of generating hydrogen is one which is as low carbon as possible, green hydrogen. It is assumed that this will be done using electricity from renewable generation, such as wind. The economics of this are not as attractive as for heat pumps, as a unit of electricity can generate 3 units of heat for a heat pump, but less than 1 unit of heat for hydrogen given the efficiency of electrolysis is maximally about 70%. Thus, for a hydrogen solution one needs over three times as much electricity to be generated. Alternative sources of hydrogen, blue hydrogen, are possible, but rely on the development and demonstration of large scale and highly efficient CO_2 capture and storage. The preferred option at present is to transport that captured hydrogen to offshore saline aquifers in the process of carbon capture and sequestration.

Thus, to deliver low carbon solutions for heat pumps and/or green hydrogen a significant amount of additional electricity generation is going to be required which could be up to a factor of four higher than presently delivered; approximately 40 MW. This will require a massive scale-up of offshore wind and solar generation, with not insignificant consequence for grid stability. The intermittency of wind and solar, where there can be extended periods of low generation is an issue if at the same moment the system is relying on that generation for heating. There is a clear need for some form of grid-scale energy storage system which can store either heat or electricity or both. The proposition that the development of electric vehicles will create a second life market for lithium-ion batteries which can be used for energy storage, or that that electric vehicles plugged into the charging infrastructure can be used for a large battery is unlikely to be a solution. The type and scale of storage required to manage the future grid will not be met by this type of battery, but rather technologies such as compressed air energy storage, CAES, or liquid air energy storage, LAES. These are in development, with potential for deployment in the next 5-10 years.

Heat pumps consume an amount of electricity which is of the scale of running several electric kettles continuously. If all houses on a street and all streets in a suburb are running heat pumps and if all the homes are also charging electric vehicles this then very quick provides an electricity demand which is higher than the rating of the local electricity grid. As a result, there will need to be significant reinforcement of the local grid infrastructure to support low-carbon heat pump heating and electric vehicle charging.

The last, main, source for delivering low-carbon heating is the Scandinavian approach – district heating. Here hot water/steam is circulated in pipes to the buildings which then circulate the heat through their heating systems either directly or through a heat exchange process. Cities such as Birmingham, Coventry and Nottingham have district heating systems serving the large municipal buildings in the city centre. Indeed, the system which serves Birmingham distributes heating, cooling and power. There is the possibility for the extension of such networks across wider swathes of cities, particularly in dense urban environments. The installation of district heating is highly invasive and needs pipework laying and is not the ideal solution in low density residential areas. The source of the heat for such systems in the UK is typically combined heat and power plants (CHP). These consume natural gas and hence are not low carbon. To make these systems low, or zero, carbon there is a need to either combust hydrogen rather than methane in the CHP engines or use sources of waste heat. Such sources could be geothermal, industrial or even from the energy from waste incinerators which are used to process municipal waste. At present most of the UK's district heating systems are not configured in this way.

It is clear then why the UK has not made so much progress in decarbonisation of heat – it is really very difficult to achieve without a simple solution that can be rolled out. These challenges were analysed, with a series of policy recommendations to assist in the CBI-University of Birmingham joint policy commission on Net-zero: The Road to Low Carbon Heat, chaired by Lord Bilimoria, published in July 2020. Among the recommendations was that there needed to be coordination across the sector to deliver heat decarbonisation – a National Delivery Body, NDB. The NDB would coordinate the national infrastructure required, the scaling up of production in terms of heat-pumps and hydrogen boilers, support the creation of national skills and training programmes to create low-carbon heating engineers, to provide the expertise such that local heat planning and heat zoning joins up into a deliverable national decarbonisation plan and also to create the right portfolio of incentives and penalties to induce change. The UK government is poised to deliver its heating and buildings strategy and it is clear there is a need to be purposeful and ambitious to accelerate what has been a slow and muddled start to heat decarbonisation.

The Midlands is proposing a National Centre for Decarbonisation of Heat, NCDH, working between local government, academic institutions, innovation Catapults and industry to coordinate the delivery, as a potential delivery arm of the NDB. The NCDH would work on a whole series of activities including driving down the cost of delivering heat. This would be the analogue of what has been achieved in offshore wind. As a benchmark of heating installation, the cost of heat pump installation for heat pump and thermal retrofit is £20,000 per house and 25 million homes, so of the order of £500 billion. An innovation programme which took just 10% off the installation costs would save £50 billion, which is a staggering amount and could be redeployed elsewhere in the energy system, or even in healthcare. The Midlands has the assets to lead decarbonisation of heat, since it is home to several major companies such as Worcester-Bosch, Baxi and Engie, state-of-the-art manufacturing expertise through the Manufacturing Technology Centre, the Energy Systems Catapult, Energy Capital and a powerful network of Midlands universities through the Energy Research Accelerator. These are some of the organisations which, along with the Green Finance Institute, are advocating the development of the National Hub for the Decarbonisation of Heat (NHDH).

Regional and national leadership in creating low-carbon heating solutions will provide massive economic potential for delivery of heating solutions and services to international markets. The BEIS clean growth transforming heating report identified an estimated £11 trillion of public and private investment will be required in the global energy sector, including heating, between 2015 and 2030 if the signatories to the Paris Agreement are to meet their national targets. Of this Ricardo Energy & Environment, in their work for the Committee on Climate Change, estimated the low carbon economy in the UK could grow 11% per year between 2015 and 2030, four times faster than the rest of the economy, and could deliver between £60 billion and £170 billion of export sales by 2030.

The CBI have called this the decade of delivery. What this captures is that we have heat pumps, we have electric vehicles, we have wind and solar and we have large scale nuclear generation and we need to stop treading water and get on and deliver. However, the journey to low-carbon heat is not going to be easy, it will require massive behavioural change and enormous national coordination. As such structures such as the proposed National Delivery Body and National Centre for the Decarbonisation of Heat will place an absolutely crucial role.

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[1] Ricardo Energy and Environment for the Committee on Climate Change (2017) UK business opportunities of moving to a low-carbon economy (supporting data tables) www.theccc.org.uk/publication/uk-energy-prices-and-bills-2017-report-supporting-research/.

Energy from waste and the circular economy

In spring 2020, Birmingham Energy Institute and the Energy Research Accelerator released their policy commission report exploring how energy from waste (EfW) can be integrated into regional and national circular economy strategies, and setting out the economic and research opportunities for the Midlands. A series of roundtable events with national and regional politicians, industry, business and environmental stakeholders accompanied the launch. These provided opportunities for feedback on the report's proposals and for exploring opportunities in both the East and West Midlands to develop systems thinking on EfW. One year on, in advance of COP26 in Glasgow, we reflect on the findings of the report and the current position of energy from waste in circular economy and net-zero strategies and policies. We alsoconsider the future opportunities for research and industrial engagement for the University of Birmingham.

The waste industry has long held that EfW is effectively carbon neutral because it displaces the production of greenhouse gas emission from landfilling waste (including the more potent GhG methane - approximately 30 times more harmful as a greenhouse gas than CO_2) to produce a necessary resource - energy. However, this argument is increasingly hard to defend because the carbon intensity of grid electricity declines as more renewable generation is brought online. As our policy commission report argued, without capturing waste heat, which only 1 in 5 UK plants currently do, the carbon intensity of EfW is second only to coal combustion due to indiscriminate incineration of all waste at EfW facilities. In particular, the incineration of non-biogenic waste, including large quantities of plastic, is where the landfill displacement argument really 'breaks down'. From an emissions perspective, we would arguably do better to bury materials that don't break down quickly rather than incinerating them in inefficient EfW plants. That said, one then needs to consider the leaching of those materials into the wider environment.

This argument was central to the policy commission report and informed the following high level recommendations: Existing and new EfW plants should exploit waste heat potential in order to significantly reduce the carbon intensity of each unit of energy produced; there should be a focus on developing second-generation EfW technologies including AD, pyrolysis and gasification, which turn waste into molecules and products, as well as energy; there should be scaled-up roll out of, and further R&D into, small-scale carbon capture technologies that turn CO_2 emissions from EfW into products.

Politically, there is a challenge for local and regional authorities considering the role of EfW as part of their energy system, portfolio of energy assets, and zero-carbon circular economy strategy. As environmental campaigners and researchers reasonably point out, retaining, and possibly expanding, EfW facilities creates a demand for waste streams to incinerate and demotivates actions higher up the waste hierarchy to reduce, reuse, repair and recycle waste rather than using it for energy recovery. There is a reluctance within some local authorities to show an ongoing reliance on EfW to deal with household and commercial waste, though others such as Leeds and Nottingham City Council already have EfW as part of their energy strategy. In the West Midlands, the Combined Authority (WMCA) have initiated 'Kickstarting the West Midlands' Circular Economy' to better understand the opportunities for developing a circular economy approach across the whole region.

There is a potential opportunity to make EfW more circular as part of a heating decarbonisation strategy; heating accounts for around 40% of energy utilisation and one third of the UK's carbon emissions. For areas of high population and building density, district heating is a preferred option. Many cities across the Midlands region have well-developed district heating schemes installed or planned. At the moment, most of these schemes are reliant on combined heat and power (CHP) plants, fuelled by natural gas. For district heating to be lower carbon and more sustainable, there is a need to transition from methane to hydrogen for heat and power generation, but most crucially, to also utilise waste heat from EfW plants.

Using waste heat from existing and planned EfW facilities should be a priority in local governments' planning and procurement processes. There are examples where this is happening: Coventry City Council have developed a scheme which transports heat from the EfW plant 6.6 km to the city centre; in Stoke, they are developing a scheme which would combine EfW, geothermal and industrial waste heat. Progress has not been universal, as evidenced by the ongoing challenges integrating the Birmingham EfW plant at Tyseley into the city's district heating system, where optimising energy recovery for both heat and power has not been incorporated into the procurement process for the future contract of the EfW plant.

This illustrates the competing challenges that local authorities wrestle with in setting priorities where net zero and energy efficiency, waste processing, and the circular economy are not considered holistically and decisions and operations remain siloed. The limited capacity of local government, due to the economies of austerity cuts, means that they have to prioritise the delivery of key services and have a reduced ability to deal with complex issues that cut across departments and political portfolios. There is a need for greater devolution to the regions of responsibility and resources to support the development of infrastructure that can simultaneously and synergistically evolve the circular economy and carbon reductions. The WMCA's 5 year plan and the associated discussions linked to devolution provide a basis for creating the required platform at the regional level to develop and deliver a circular economy and net-zero plan across the West Midlands.

Even with better utilisation of the waste heat from EfW plants, there will continue to be questions about the sustainability of incineration for waste processing. Greater segregation of household and commercial food and organic waste will enable a reaccelerated roll out of anaerobic digestion and the production of biogas to displace natural gas. This may be an option for CHP plants, alongside the production of hydrogen using steam methane reforming as the hydrogen economy grows. The digestate from anaerobic digestion can also be used in the production of fertilizer in a process which captures CO_2. In addition, the removal of the organic fraction from waste streams reduces the production of methane, which, from an emissions perspective, makes landfill more attractive.

EfW clearly does have benefits, as outlined, if the energy potential is fully captured into the energy system. Increasingly, this means focussing on heat rather than electricity. However, for EfW to be fully circular efficient and affordable, carbon capture technology for EfW facilities and technologies will need to be developed. The recent announcement that Veolia will work with Carbon Clean to become the first UK operator of EfW facilities to demonstrate the latest carbon capture technology is an important development for the sustainability of this sector and the evolution of EfW towards zero carbon.

The UK Government's Ten-Point Plan for a Green Industrial Revolution provided a strong vision towards net zero, with a heavy focus on hydrogen, nuclear, offshore wind, the natural environment and other key sectors. However, it is rather quiet on how to integrate the circular economy. As the Birmingham Energy Institute and Energy Research Accelerator's *Energy from Waste and the Circular Economy report* identified, there are plenty of ways that the benefits of a circular economy can be integrated into energy systems, and indeed, would benefit the Ten-Point Plan.

Production of hydrogen and substitute transport and aviation fuels are both possible from the processing of plastic, biomass and organic waste streams through pyrolysis and gasification processes. There are a number of companies who are scaling up the demonstration of such technologies, ensuring that they are both economically and commercially viable. Pyrolysis is a difficult process to manage due to the thermal environment required and the residues created. As a result, it has had a slightly tortuous journey to commercialisation. Even now, funding has typically been for the capital development of the plant, and has not extended to the operational costs of performing the extended validation tests required to de-risk the proposition for investors. This is a fundamental weakness in the UK's approach to the transition of this sector and there is a risk that UK companies leading in this sector will not reach full commercialisation. One year on from the publication of the policy commission report, there remains a strong need for a national coordinated support programme for this sector to ensure that a key element of the circular economy and energy from waste is delivered.

Many of the benefits of integrating the circular economy and energy and fuels production can only be found through co-location of technologies, waste streams and consumers. The Resource Recovery Cluster (RRC) concept set out in the policy commission report shows how co-location means that the waste heat and gases from EfW processes can be inputs to other processes. They can also be maximised to be of greatest value in terms of energy vectors, whilst reducing the need for transportation and subsequent efficiency losses. There are several emerging examples of this type of synergistic operation. Tyseley Energy Park (TEP) has a biomass plant that gasifies waste wood, creating green electricity, which in turn is distributed on-site through a private wire. A low-carbon refuelling station at TEP has a 3 MW electrolyser for the production of hydrogen for vehicles, including a hydrogen bus fleet, powered using the green electricity.

TEP is also the location for the Birmingham Energy Innovation Centre (BEIC) and a business incubation facility, which again can utilise the green electricity produced by the biomass plant. The BEIC will house a range of energy technology programmes including energy storage and hydrogen and fuel cells, and will provide a support platform for a waste-to-fuels programme in collaboration with the Fraunhofer Institute. Another key research development at TEP is battery and magnets recycling, with University of Birmingham academics developing techniques for the recycling of electric vehicle lithium-ion batteries and rare earth element magnets from motors and wind turbines. The ability to integrate these research programmes in one place enables the exploitation of TEPs different energy vectors, including green electricity, heat and hydrogen. The business incubator will accommodate SMEs who are developing new energy or waste processing technologies. The site is growing organically into a RRC.

Post-industrial sites are ideal locations for RRCs. The policy commission focussed on East Midlands coal power stations nearing the end of their life, but with significant infrastructure, such as high-capacity grid connections, which could be redeployed and developed as RRCs. Ratcliffe-on-Soar is one such location and the site owners, Uniper, are currently looking into developing an ecosystem around an EfW plant that would include hydrogen production. This site is ideally located next to East Midlands airport, the M1 and M42 intersection and lies adjacent to the HS2 extension. The development is integrated into the plans of the East Midlands Development Corporation and links to the Freeport application.

Locations such as Tyseley and Ratcliffe have the potential to transform the way the Midlands manages its resources, waste processing and energy production, creating ecosystems that support R&D, business growth and the commercialisation of innovative technologies, and with knock-on social, environmental and economic benefits for the surrounding area and communities. These sites can become beacons for the rest of the UK, showcasing how energy from waste can be fully integrated as part of regional circular economy and net-zero strategies and solutions.

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Green ammonia: from fertiliser to sustainable fuel

In this discussion paper, we explore the potential of 'green ammonia' to not only decarbonise fertiliser production, but also pave the way for an environmentally cleaner energy system and facilitate our transition to a renewable energy-based global society.

Why do we need green ammonia?

Ammonia (NH3) – the major ingredient of agricultural fertilisers that helps feed nearly half the world's population – is one of the most important chemicals for sustaining human life on the planet. However, its manufacture is responsible for around 2% of the global carbon dioxide (CO_2) emissions, a greenhouse gas that is the primary driver of global climate change. Its carbon footprint per tonne is significantly higher than other high production volume chemicals. This is because the process currently relies on fossil fuel feedstocks. Therefore, a new 'green ammonia' production process with net-zero carbon emissions needs to be implemented.

Ammonia is manufactured by reacting nitrogen and hydrogen gas together. As the most abundant gas in the atmosphere, nitrogen can be easily separated from air. Conversely, hydrogen does not occur naturally in substantial amounts and needs to be extracted from other sources. In current ammonia production, hydrogen is extracted from fossil fuels, with carbon dioxide as a by-product. Consequently, ammonia production cannot be decarbonised simply by transitioning the electricity grid to low-carbon energy. If we are to minimise the carbon footprint of ammonia production, there must be a transition towards green ammonia whereby hydrogen is generated from the use of renewable electricity to split water. In this way, green ammonia is manufactured from a feedstock comprising air, water and renewable electricity, making it an environmentally clean and widely-accessible process.

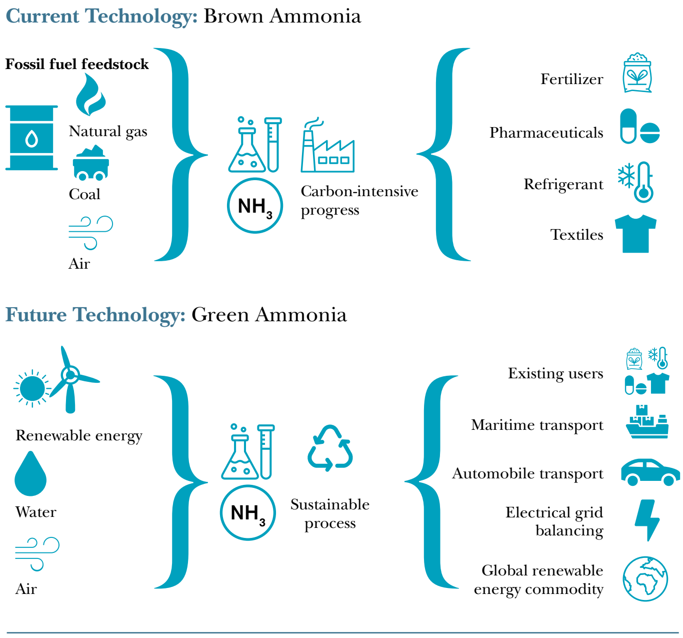

Figure 1: A comparison of existing ammonia production with the green ammonia production process.

What are the opportunities for green ammonia use beyond fertilisers?

While the decarbonisation of ammonia production for fertilisers is already critical to meeting net-zero emissions targets, green ammonia also has immense potential to serve as a next-generation zero-carbon fuel. In this way, it represents a highly-flexible way of storing renewable energy and a key complementary technology to direct electrification. Ammonia is easily stored as a liquid using modest pressure or refrigeration; in this form, its energy density per unit volume is around 40% that of petrol. This makes it an attractive energy storage mechanism for long-duration energy storage or large amounts of energy, and a possible solution to the longstanding challenge of storing hydrogen cheaply.

Transportation: Ammonia can be used directly as a fuel – burnt in an internal combustion engine – or 'cracked' to release its stored hydrogen to power electric cars, buses and trains. This flexible end-use of ammonia has prompted serious consideration of its use in the transportation sector. The maritime industry, which currently relies almost exclusively on heavily polluting oil-based fuels is actively exploring the use of ammonia as a direct fuel. Critically, there is potential to retrofit existing two-stroke maritime engines for ammonia use, which provides a viable pathway to decarbonising long-lived shipping vessels. Furthermore, by circumventing the challenge of storing hydrogen in very-high-pressure tanks, ammonia may also provide a cost-effective refuelling infrastructure for hydrogen-powered vehicles.

Grid-balancing: The demand for electricity tends to fluctuate throughout a day, and across different seasons in a year. In the UK, for example, energy demand increases by around one third during the winter months. The electricity distribution grid must be able to respond to these varying demands. In a renewables-based grid, this is challenging because of the inherent intermittency of solar and wind power. Consequently, energy storage technologies are indispensable to the smooth functioning of power distribution networks, storing energy during times of excess, ready to use when demand outstrips supply. A chemical fuel like ammonia, with high energy density and straightforward storage requirements, is well placed as a long-duration energy store, complementing the rapid response which can be achieved with batteries and pumped hydro.

Renewable energy commodity: The cost of renewable electricity now largely depends on the quality of the wind/solar resource. However, connecting remote areas with outstanding renewable energy resources to markets looking for cheaper energy is a key challenge when it comes to take advantage of those cost variations. Unlike hydrogen, which is also actively explored as an energy store, ammonia does not need to be stored under very high pressures or very low temperatures, leading to lower transport costs. Furthermore, being an already widely manufactured industrial chemical, a robust global ammonia distribution infrastructure at the megatonne scale is already in place, which can be harnessed to unlock the enormous potential of this market. Because of this, ammonia has great potential to act as a global renewable energy commodity.

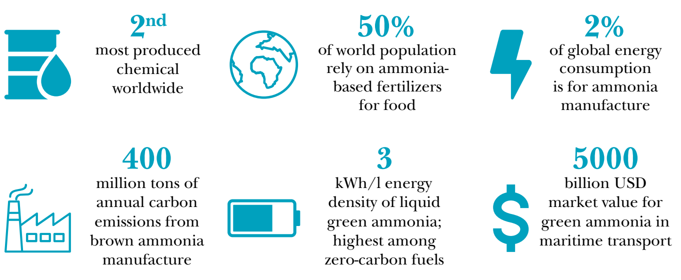

Figure 2: Ammonia: key facts

Where are the applications of green ammonia being demonstrated?

The diverse applications of green ammonia, as outlined above, have evolved beyond the stage of conceptualisation, with several pilot-scale demonstrations now being reported:

- MAN Energy Solutions has released plans for a commercially-available two-stroke engine running on ammonia by 2024, and a retrofit package for existing vessels the following year.
- A consortium led by Siemens built the Green Ammonia Demonstrator, based at the Rutherford Appleton Laboratory in the UK, which is one of the first systems to demonstrate the viability of small-scale green ammonia production and the full cycle of power-ammonia-power.
- Yara, one of the world's leading fertiliser companies, has partnered with ENGIE to test green hydrogen technology for ammonia manufacture in their facility in Western Australia. In the same region, the 'Asian Renewable Energy Hub' project, which began in 2014, continues to make rapid progress. The 26 GW renewable energy project will include an annual green ammonia production capacity of nearly 10 million tonnes, and would approximately double Australia's installed renewable electricity capacity in a single project.
- In the Netherlands, Yara has teamed up with Ørsted, a renowned offshore wind developer, with the aim of manufacturing 75000 tonnes of green ammonia per year. Companies like Haldor Topsoe and Maersk have also recently unveiled plans for green ammonia projects.
- Air Products has partnered with the Saudi Arabian Government to announce a 4 GW solar project at NEOM which will produce green ammonia.

By no means do the projects cited above constitute an exhaustive list of green ammonia projects worldwide, yet they illustrate the growing global interest in the technology, which has now started to reverberate in government policies too. The Japanese Ministry for Economy, Trade and Industry's roadmap for fuel ammonia targets green ammonia imports of 3 Mt by 2030 to support co-firing in power plants and shipping fuels, increasing to 30 Mt by 2050. While the Indian Government is set to invite bids for green ammonia projects in 2021, the German Government is financing a feasibility study into ammonia-based hydrogen transport as part of its ambition to invest 9 billion euros in green hydrogen for industrial use. Likewise, the Canadian Government recently led the development of a hydrogen strategy for the country, which integrates aspects of green ammonia to achieve net-zero emissions by 2050.

What challenges need to be overcome?

Notwithstanding the appreciable technological progress and increasing governmental policy focus on green ammonia, there are a few key barriers that must be overcome for the technology to become a prominent strategy in the pursuit of decarbonisation. The first of these challenges is posed by the 'scale' on which green ammonia would need to be manufactured. The current annual global production of 'brown' ammonia is over 175 million metric tonnes. This capacity, which primarily caters for the production of fertilisers, might appear to be significant; however, in order to decarbonise maritime transportation alone, replacing the energy content from existing fuels would require almost all of the current global ammonia production volume. Therefore, green ammonia would need to be manufactured in substantially larger quantities, and this would possibly require the proliferation of small-scale production facilities that have good access to renewable electricity to complement the traditional, centralised, large-scale nature of ammonia manufacture.

Given the urgency to decarbonise, the deployment of green ammonia production would need to be achieved in a relatively short timeframe. Encouragingly, much of the necessary technology exists to be able to begin this transition. What is needed now is support for projects which combine these existing technologies to the green ammonia supply chain: demonstrating the viability of green ammonia production, direct ammonia fuel in combustion engines and gas turbines, and ammonia cracking units which can supply high-purity hydrogen for fuel cell vehicles. There will be immense downward pressure on the cost of the final energy delivered, particularly if green ammonia contributes to decarbonising heat and grid-balancing applications. Efforts to produce technologies which integrate different energy storage processes to improve overall efficiency should be prioritised. Public and private support for these projects, including through the use of subsidy schemes such as those which have so effectively promoted the deployment of wind and solar energy, will help drive down costs and meet the challenging pace of transition required. Similarly, implementing accredited standards for the carbon footprint of fertilisers and fuels derived from ammonia may help generate a consumer drive for sustainable ammonia products.

While ammonia's potential contributions as a zero-carbon fuel are clear, its corrosive nature and the toxic impacts of its uncontrolled release into the environment must be considered in any expanded use. Efforts to minimise excess nitrogen release through the use of fertilisers remain a critical environmental stewardship focus. In contrast to use in agriculture, the uses of ammonia as a sustainable fuel would only be designed to release harmless nitrogen gas back into the environment. The existing safe practices for handling and transporting ammonia can be readily applied to these new contexts. Nevertheless, appropriate regulations from governments which enable the use of ammonia in energy applications, but also ensure safety and minimise any emissions of ammonia or nitrogen oxides must be developed.

Of course, research and development focused on improving the economic competitiveness of green ammonia will be critical. Scientists in academia and industry continue to work on these aspects. These include initiatives such as developing improved catalysts for ammonia production and cracking, entirely new paradigms for ammonia production directly from air and water, as well as better process integration. For example, there are potential synergies between different energy storage technologies, such as liquid air energy storage and green ammonia production, which may improve overall cost and efficiency.

There is also a clear argument for extensive public outreach for the concept of green ammonia. For instance, the substantial carbon footprint of agricultural produce that the general population consumes often gets overlooked. With regards to next-generation transportation, electric vehicles have become a topic of active discussion in the public domain, and so has green hydrogen as an alternative fuel.

It is important that green ammonia now enters this conversation more prominently. Besides educating the general public about ammonia's potential to be a transportation fuel, such a discussion will also allow addressing public perceptions of the risks associated with using ammonia.

Summary

Green ammonia has enormous potential in the grand global challenge of decarbonisation. The technology will continue to help us feed the world's growing population but at much lower environmental impact. By virtue of being a hydrogen and energy store, ammonia can feature in wide-ranging applications, including being used as a transportation fuel and for grid balancing. Despite numerous demonstration projects being underway, there are several barriers that currently preclude the manufacture and use of green ammonia on a global scale. Overcoming these barriers will require government initiatives and public engagement to complement R&D efforts. Meeting the world's increasing energy needs and reducing carbon emissions do not need to be mutually exclusive, and green ammonia shows that both these demands can be met. The versatility of green ammonia to be an alternate technology in many of the leading carbon-intensive sectors makes a stronger case for a greater dialogue among policy makers and the general public. The mission of achieving net-zero emissions by 2050 is highly challenging but one that is essential. And without green ammonia being deployed on a large scale, succeeding in this global mission will be all the more difficult.

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Thinking circular: how to avoid the pitfalls in transitioning to net-zero emissions

From the Paris Agreement in 2015 to the agenda for the upcoming COP26 in November, there is a growing consensus that to resolve the climate emergency means making net-zero emissions a priority at international, national, and local levels. Governments, academia, emissions experts and businesses are all working on solutions that will help balance the amount of global greenhouse gas (GHG) produced and the amount removed so that overall emissions are 'net-zero'.

For example, the UK was the world's first major economy to pass net-zero emissions into law by 2050. And in 2020, the UK government published its ten-point net-zero emissions strategy, which included plans to accelerate the shift to net-zero emission vehicles (EVs), ban sales of petrol and diesel cars, and decarbonise the transport sector by 2030.

However, the systemic adoption of zero-emission technologies has created a significant shift in demand for natural resources, causing many cross-boundary sustainability issues within the value chain of the manufacturers of these technologies. The mining of critical raw minerals required for electric vehicle batteries, for example, damages the livelihoods of people living in nearby communities, causing water stress and scarcity, environmental pollution and issues of forced labour.

Where we are now

Given these problems, any responsible business model needs a detailed understanding of the sustainability footprint of its value chain, including all three GHG emissions scopes. Scope 1 emissions are direct from a company's operations, and scope 2 are indirect emissions from purchased energy. Scope 3 are divided into upstream emissions that are from a company's purchased goods, supply chain, employee travel etc., and downstream emissions from the processing and use of a company's products after the sale.

Setting ambitious targets is one thing and delivering against them is another. Unfortunately, at the moment, net-zero emissions is a nebulously defined concept and many companies still only account for scope 1 emissions direct from their operations. There is currently no shared pathway for businesses to align with the Paris Agreement to limit global warming to 1.5 by 2030, considering a company's entire value and supply chain emissions. Likewise, there is a lack of accounting mechanisms that incorporate a circular economy approach necessary to evaluate the GHG emissions and sustainability impacts of different global value chains.

Most policy and regulatory frameworks underplay the essential role of accounting in achieving a circular economy (CE) and the global shift to net-zero emissions. Using a CE accounting approach can reduce the negative impacts of silo and linear thinking, open up new possibilities for transitioning to a net-zero economy, and help a business manage its value chain as a series of interrelated activities that positively and negatively affect each other. It also allows for a fuller representation of a business' production and consumption value chains and how they relate to individuals and institutions.

Like in natural ecosystems, waste is reused and regenerated in a continuous loop in a CE model, helping a business identify how and where to use resources more efficiently and effectively. But a CE approach won't automatically result in the most sustainable solutions for manufacturers of net-zero emissions technologies unless their accountants and sustainability experts map the entire product value chain and its global sustainability impacts across different sectors in their decision-making processes.

Where we want to go

Suppose a mass transition to EVs is key to helping the world deliver on the climate change commitments in the Paris Agreement and tackle air pollution from road transport. In that case, mechanisms must be developed capable of monitoring and addressing the EV industry's impacts across different sectors – from the mining of raw minerals for making batteries to the use of renewable energy for customers charging them from the grid.

The first stage in this process is to analyse GHG emissions for the industry across all three scopes, identifying which activities are core and have the most significant impact on emissions. Secondly, by undertaking what's called a 'nexus analysis', you can map all the relevant flows of the materials and resources used in EV production and consumption – from initial extraction to end-of-life disposal – showing where mining, cleaner energy and EVs structurally intersect each other. It's at these intersections where critical decisions, conflicts and potential changes are most likely to occur.

Understanding where different institutions are positioned relative to these critical intersections will provide valuable insights into their dependencies, powers and agency to transform the value chain of any net-zero technology. For instance, the mass adoption of EVs will require a substantial increase in the mining of cobalt, manganese, nickel and copper, and investments in charging infrastructure and renewable energy sources. Therefore, a CE accounting model will need to consider all these different upstream relationships in the EV global value chain and attempt to geographically unbundle and holistically remodel them as part of a broader industrial ecosystem.

Without this kind of CE accounting and nexus analysis, there is a real risk that the transition to net-zero emissions required by the Paris Agreement could, in fact, end up adversely impacting human rights, the natural environment, climate change, air pollution and local communities within the value chain of net-zero technology companies. That's why this approach must be encouraged and formalised in policies, frameworks and international charters for net-zero emissions. And new digital technologies, like Blockchain and life cycle assessment mechanisms such as ISO 14040:2006, are already helping provide better tracking and verification of materials within a circular economy to help monitor supply chains labour issues and account for carbon emissions from all relevant processes following a product entire life cycle.

Ultimately, this way of circular thinking can help transform the current problems of net-zero emissions transition planning and management into opportunities to address a whole range of underlying and interconnected social, technological, ethical, environmental and political issues that will benefit the entire COP 26 agenda for a more resilient and sustainable world.

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Clean transport

04

Clean air: bringing local synergies to the global climate challenge

"Clean Air", measures to reduce carbon emissions, clean air zones, electric vehicles, net zero, global warming – this now-familiar terminology is often conflated in public understanding and sometimes mixed up in policy ambitions, obscuring valuable co-benefits from what should be complementary strategies.

This is not just semantics: there are many policy win-wins between climate and air pollution measures, but also some tensions – and these benefits and tensions arise differently geographically, and hence, electorally. For many air pollutants, changes in local behaviour deliver local air quality improvements and hence improve the health of the local population – while tackling the climate challenge requires reductions in the growth of global carbon dioxide concentrations.

Recent polling by Climate Outreach revealed that 87% of people were very or somewhat worried about climate change, with 50 - 94% of respondents accepting that climate change was "real and caused by human action". However, significant proportions (up to 40%) felt that we should "focus on protecting the environment at home", rather than global engagement. Importantly, there is a strong correlation between the groups which are least engaged with the climate challenge, and those who support a local focus for environmental improvement. Being clear over the distinctions and complementarities between climate change and air pollution allows us to prioritise the biggest policy wins overall, and can make behaviour change more relevant to the communities involved and impacted, increasing their agency and engagement. Here we unpick the distinction between climate and air pollution, and their contrasting geographies of effect. We illustrate the scope for regional policy win-wins focussing upon transport measures in the West Midlands.

Climate change: mostly global

Climate change – the increase in global mean temperatures, changes in weather patterns, and ocean acidification – is primarily driven by increasing concentrations of long-lived greenhouse gases, of which carbon dioxide (CO_2) is the most important. "Long lived" here means that carbon dioxide lasts for many years in the atmosphere (more precisely, whilst the carbon is cycling between the atmosphere, oceans and biosphere). Carbon dioxide mixes around the planet through the atmosphere, and carbon dioxide levels in the air above Birmingham are similar to those above Beijing and above Bermuda – the atmospheric levels reflect integrated global emissions.

Climate policy related to carbon dioxide is a global challenge, requiring international approaches such as the Paris Agreement and COP26. The environmental science reality is that individual countries or cities cannot control the CO_2 levels in their atmospheres – or the climate change they will experience – through national actions alone. This framing of the climate challenge as a tragedy-of-the-commons issue, with narratives of intergenerational and geopolitical inequity tensioned against (near-term) economic cost has hindered progress and public (and hence political) palatability of action. Why should I change my lifestyle to reduce emissions, at cost to me, when my geopolitical neighbour isn't doing the same? This narrative can change when we consider air pollutants species which are present in the air at levels harmful to human or environmental health (carbon dioxide is not directly harmful to health at the levels usually encountered in outside air).

The Air We Breathe

In urban environments, the key air pollutants driving health impacts are fine particles suspended in air, and nitrogen dioxide gas (NO2). Airborne particles include PM2.5 – the fraction of particulate matter (PM) less than 2.5 micrometres in diameter, around 1/50th the width of a human hair, small enough to be inhaled into our lungs. In the UK, the combined effects of long-term exposure to nitrogen dioxide and PM cause 24-36,000 excess deaths each year, and air pollution was recently identified as a material cause of death for the first time in a Coroner's Report, in the case of 9-year-old Ella Adoo-Kissi-Debra.

The dominant source of nitrogen dioxide in urban environments is local road traffic exhaust emissions – especially from older and diesel vehicles – with smaller contributions from industry, power generation and other activities. The main PM emission sources are combustion – domestic solid fuel combustion, industrial combustion, road transport (exhaust and non-exhaust) and industrial processes, alongside agriculture and natural components. A significant proportion of PM is formed in the atmosphere from gases, which, in turn, derive largely from road transport, power generation and industrial combustion. There is therefore very strong overlap between many of the sources of air pollution (i.e. combustion) and of anthropogenic carbon emissions (i.e. fossil fuel combustion).

Air pollution: all politics is local

However, the geography of air pollution differs: atmospheric chemistry removes nitrogen dioxide from the air, on a timescale of 12-24 hours. If we reduce traffic emissions in a given city, nitrogen dioxide levels in that city will fall, and health benefits to the local population will result. To use the example above, Birmingham can improve its air quality without needing action in Beijing, or in Bermuda. Airborne particles last a little longer – they are removed by processes like rainfall and deposition to surfaces, and persist for a few days in the lower atmosphere – so a regional-to-national approach is needed.

This means that local, regional and national action to tackle many key carbon emissions – e.g. fossil fuel combustion for heating, industry, power and transport – also address many of the dominant local and regional air pollution sources. As the air pollutants have much shorter lifetimes, local changes leading to reductions in their local emissions give rise to lower local concentrations and improved health outcomes for the local population – a subtly different proposition to encourage action.

Transparent communication of the air quality benefits from climate / net zero measures can increase the support for difficult policy choices, and more accurately account for the secondary benefits that many such measures have. While formal methods exist to account for the air quality co-benefits of carbon emissions reductions, there is limited wider appreciation of the distinction between the climate and air pollution geographies. Indeed, images of cooling towers (releasing water vapour, i.e. harmless clouds) are recurrent in news stories regarding air pollution – and the local/regional nature of the air pollution footprint is often neglected.

Assessing the benefit

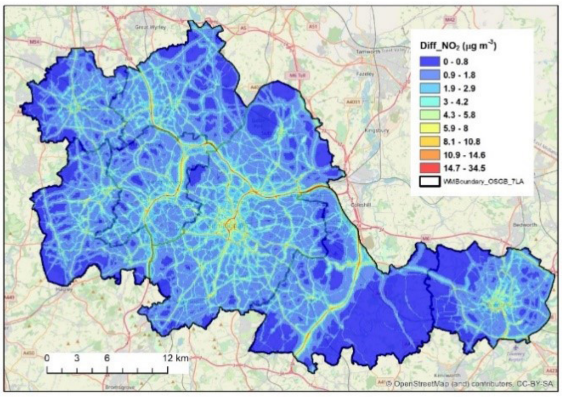
Surveys have found that air pollution concerns resonate, and images of air pollution have been found to be the most effective in visually communicating the health impacts of climate change; – 75 % of respondents say that air pollution was the climate impact they felt they could do most about personally – compared to, for example, 6 % in the case of floods. However, quantifying the air quality / climate interactions can be challenging.

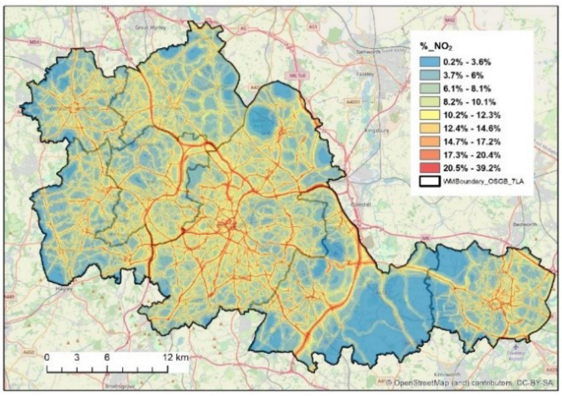
In the West Midlands, the University of Birmingham's WM-Air project[1] has been working with the West Midlands Combined Authority (WMCA) to quantify and illustrate the air-quality co-benefits of net zero policy options, aligned with the WMCA's commitment to achieve net zero by 2041. A key aspect of regional decarbonisation is transport strategy, including bus, car and light vehicle electrification – as transport accounts for 36% of West Midlands carbon emissions. In parallel, many areas in the region experience elevated nitrogen dioxide concentrations (leading to significant health and economic impacts, outlined in a recent CBI report, and driving policy responses such as the Birmingham Clean Air Zone).

[1] WM-Air is a five-year project programme of activities to apply the latest research science to deliver regional impact - in societal, economic and policy terms - in support of improved air quality and health across the West Midlands. WM-Air is led by the University of Birmingham, funded by the UK Natural Environment Research Council, and delivered through a portfolio of projects with external partners.

Financial support from NERC (NE/S003487/1) and the University of Birmingham Institute for Global Innovation.

Here we show the air quality co-benefit for an achievable vehicle electrification scenario, focussing on service vehicles. If the region's buses were electrified, and 50 % of light delivery vehicles converted to electric, the WM-Air air quality model predicts reductions in annual mean nitrogen dioxide concentrations of 15 – 35 g m^{-3}, or 20-35 %, could be achieved. These results probably underestimate the air quality benefits, as the light delivery fleet has expanded significantly with final-mile-delivery of online shopping during Covid.





Impact of bus electrification + 50% light vehicle electrification (total traffic levels unchanged) on annual mean nitrogen dioxide concentrations across the West Midlands. Upper panel: Reduction in annual mean nitrogen dioxide; Lower panel: percentage change vs Business-as-Usual scenario. We assume no impact of the power generation source, i.e. remote or renewable electricity generation.

A more complex picture

We have highlighted one aspect of the air quality-climate interchange, emphasising the local pay-off in terms of air pollution and health from actions which effectively tackle the climate challenge. There are many more nuances to this story – some of which represent policy tensions rather than win-wins (for example, diesel vehicles typically have lower carbon emissions than their gasoline equivalents, but higher air pollution emissions) and which are detailed elsewhere.

Further exploration of scenarios such as that shown above can unpick issues of environmental equity and justice. In the example above, focussing on bus route electrification tends to concentrate the air pollution reduction benefits to areas of the highest population density; prioritising light delivery vehicles achieves an even greater reduction in exposure – but lower gains for the most polluted locations which tend to correlate with the most disadvantaged communities. The air pollution co-benefit from climate policy can then become a measure of policy prioritisation, a tool for local environmental improvement, and a mechanism addressing local environmental health inequalities.

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Embedding climate change adaptation as business as usual within the railway sector

Extreme weather impacts railway operations causing damage and disruption for passengers. As railway infrastructure (e.g. bridges, embankments) is often longlife (50+ years), it must be resilient to current weather and future climate to enable safe and efficient railway operations. Under the Climate Change Act, Network Rail are mandated to assess their weather and climate resilience, and in 2020 provided their second iteration of plans. This article will examine the efficacy of these new Weather Resilience and Climate Change Adaptation plans against international best practice, and offer recommendations on how Network Rail and the broader transport sector can embed climate adaptation within business as usual. It will present a globally leading framework for climate adaptation that enables any organisation, regardless of its size or climate preparedness to begin the process of adapting to climate change.

Victorian infrastructure and climatechange

If you travel from Bristol Temple Meads to London Paddington along the Great Western Railway, your journey will take you through Box Hill Tunnel (originally the world's longest railway tunnel), over Maidenhead Railway Bridge (Figure 1), on a route that was designed and constructed by the famous Victorian engineer, Isambard Kingdom Brunel between 1830 and 1850. This historic infrastructure predates climate change, and during its construction in preindustrial times, the annual mean UK temperature was approximately 1°C cooler than in the recent decade.

Despite the many declarations of climate emergencies, and current climate pledges and policies to achieve net-zero, global temperatures are likely to be 2°C warmer by 2100. A global warming of more than 1.5°C as compared to pre-industrial levels is associated with the more dangerous impacts of climate change, such as increased frequency of extreme weather and greater sea level rise. UK Climate Projections show that in the future, the UK will have hotter, drier summers and milder, wetter winters. Extreme weather, such as heavy rainfall events or hot summer temperatures are becoming more frequent. Summers like 2018 could happen every other year by 2050. Within this general pattern of climate change there are regional variations; for example, the greatest summer temperature increases and summer rainfall reductions are projected for southern England. Extreme temperatures can cause assets to overheat and become unreliable and heavy rainfall can lead to flooding, landslips, or material washout onto tracks. Slower changes, such as the increased desiccation of clay soil embankments due to hotter drier summers can impact slope stability or track geometry. Sea level rise towards the end of the century may lead to closure or rerouting of some of our coastal railway sections, as the annual cost impact of coastal flooding and storm surges make existing routes no longer operationally viable.

As such, infrastructure operators and owners such as Network Rail must adapt to a changing climate. The railway network is integral to modern society, and weather-related disruption causes wider socio-economic impacts. For example, the closure of the Devon coastal railway line for two months following storm damage at Dawlish in 2014 is estimated to have cost the local economy up to £1.2 billion. Many of us have stories of long journeys home following "no trains north from Euston" or a "bus replacement services between Oxenholme and Edinburgh Waverly". Most seriously, weather damage to railway infrastructure has the potential to cause derailment and loss of life as in the Stonehaven tragedy 2020, when heavy rainfall was linked to the washout of stones onto the railway line.

Adapting our railway infrastructure is no easy task; the railway network is composed of many different assets of different ages and lifespans, which are vulnerable to different types of weather, and are located in different parts of the country with different geography and geology that experience different types of weather and extreme weather, and different future climate change.

Weather resilience and climate change adaptation (WRCCA) at Network Rail

Under the Adaptation Reporting Power (ARP) set out in the 2008 Climate Change Act 2008, the Secretary of State can request that infrastructure operators such as Network Rail report on how they are addressing current and future climate impacts. This feeds into the UK Climate Change Risk Assessment, and the National Adaptation Programme. Although the process is not currently mandatory, Network Rail have committed to reporting on their progress and action via the five-yearly ARP process, supported by information and evidence from their Weather Resilience and Climate Change Adaptation (WRCCA) strategy.

Network Rail are implementing their WRCCA strategy through eight Route level action plans, where a 'Route' is a Network Rail area of operation such as the 'Southeast' or 'Northwest and Central'. This regionalised approach helps to address the differences in geology, geography and regional climate across Great Britain. The first iteration of the Route WRCCA plans were produced in 2014 (for the 2014-19 period), and these were updated around 2020 for the 2019-2024 planning period. Each WRCCA plan follows the same format for a particular route. The plan initially describes the geography and climate of the Route, to undertake a vulnerability assessment of the Route to current and future weather. For example, it considers how weather, such as maximum temperature, or the consequences of weather, such as increased river flows linked to increased rainfall, will change in the future, along that particular Route (Figure 2). Information on climate change and changing river flows are provided by the Met Office and Environment Agency. The following impact assessment outlines how weather and future climate change can impact different types of assets, such as track, signalling, or buildings. Past performance measured using delay to schedule information (Figure 3) is used to attribute delay minutes and delay costs (the compensation paid out to delayed passengers) to different types of weather along that particular Route. This quantifies the impact of different types of weather or weather hazard for different years and different Routes. Finally, each plan outlines a series of actions to improve the resilience of the Route to weather and climate, and the investment available for the planning period. These might include 'hard' adaptation actions, such as asset renewals or repairs, or 'soft' adaptation options such as liaising with other stakeholders such as the Environment Agency to reduce flood risk.

Climate resilience and adaptation on the global scale

Railway infrastructure often has a lifespan of multiple decades. Globally, the climate is changing, and extreme weather and linked hazards such as wildfires and flooding are increasing. It is therefore imperative that railway organisations embed climate adaptation within their business as usual for failure to consider climate change can lead to increased costs or delays in the future. Indeed, the European Union Climate Change Adaptation strategy requires infrastructure operators to undertake resilience assessments as a condition of receiving funding from the European Regional Development Fund and Cohesion Fund. For example, in Slovakia, climate change risks and vulnerabilities were considered in the modernisation of a key passenger and freight railway corridor. This example and others are shared in the EU Climate-Adapt portal which features more than 100 case studies of adaptation from across Europe. Both SNCF (France) and Deutsche Bahn (Germany) have high-level strategies for climate change adaptation.

In order to support sector-wide adaptation to climate change, the Rail Adapt project led by Birmingham Centre for Railway Research and Education (BCRRE) for the International Union of Railways (UIC) collaborated with global transport stakeholders to develop a framework for climate change adaptation that can be used by any organisation, regardless of its current level of climate change awareness (Figure 4). The two-sided framework comprises an adaptation strategy and an implementation plan. The process is circular and iterative which is crucial to incorporate new information and change. This could include new climate information (climate projections evolve in detail and precision), changes to resilience (assets are renewed, assets deteriorate, hazards change), or organisational change (changes to governance or company structure). The Rail Adapt Framework also encourages links with stakeholders, in different parts of the same organisations, and in other sectors. Railway infrastructure rarely operates in isolation, and has interdependencies with the energy sector, who provide power for railway operations, and the ICT sector (Information and Communications Technology) who enable communications. Infrastructure is only as strong as its weakest link, and failure at a critical node, sometimes referred to as a "single point of failure" can lead to cascade failures across multiple infrastructure sectors. For example, the flooding of an electricity supply substation in Lancaster in December 2015 left the city without power for over 30 hours and affected all critical infrastructure including road and rail transport, ICT, water supply, and emergency services.

Next steps for Network Rail

A comparison of the WRCCA plans with the Rail Adapt framework shows that Network Rail are making good progress at embedding climate adaptation within their business as usual. The WRCCA plans include many core adaptation concepts, such as identifying hazards, vulnerabilities, and losses, and generating action plans. Our research with transport operators indicates that Network Rail are leading the way globally, and that the WRCCA plans should be considered an international example of current best practice in this area. However, in this developing area of infrastructure adaptation to climate change there are opportunities to improve and refine the process. A recent review by BCRRE and Climate Sense highlighted two key areas where the WRCCA plans can be improved, ultimately to increase railway resilience.

Firstly, future iterations of the WRCCA plans should broader in scope and consider interdependencies and interacting risks with other sectors (such as energy supply), and greater extremes of weather and longer-term climate change, including high-level low-probability climate change. This would require greater collaboration with external stakeholders such as local authorities and flood resilience groups at Route-level to support the WRCCA plan development process, but also at a strategic level to align climate resilience agendas across the UK. Network Rail are a member of the Infrastructure Operators Adaptation Forum, an interdisciplinary UK-wide group that facilitates knowledge exchange between senior professionals working in this area, across multiple sectors including national and regional government, to share tacit knowledge provide a collaborative approach to adaptation. Network Rail should also incorporate high-level low-probability climate change, or so called 'worst-case' scenarios within their adaptation planning, not least as this is the current government recommendation for sea-level rise.

Secondly, the implementation of the WRCCA plans requires further development to provide greater clarity on option analysis and governance, and to demonstrate line of sight from adaptation needs to asset management. All WRCCA plans provide options to improve resilience, but the rationale behind the prioritisation could be clearer and more consistent. Moreover, following the recent organisational restructure at Network Rail the ownership of the WRCCA plans needs to be restated. More generally, the organisation of investment and planning into five year blocks (known as Control Periods) disconnects with the longer-term view required for effective adaptation. Adaptation pathways, a means by which to plan for long-term change but prioritise short term needs are a potential way forward.

These suggestions for Network Rail improvement highlight the importance of the circular approach to adaptation shown by the Rail Adapt framework that allows for changes to become incorporated within adaptation.

Conclusions

The Great Western Railway, with its historic Brunel engineering serves as a useful reminder of the longevity of our railway infrastructure, and the need for long-term infrastructure adaptation planning. It also predates climate change, and as such was designed for a climate that no longer exists. The Great Western Railway and similar Victorian infrastructure are poignant reminders of how quickly rapid industrialisation produced the carbon emissions that changed our climate.

Today, the railway infrastructure is the backbone of modern society, transporting people and freight around the country. It is an important part of climate mitigation and efforts to meet net-zero by 2050 because rail travel produces far less carbon emissions than travel by private car. The railway network must also be resilient to future weather and climate change. The adaptation challenge facing Network Rail is clear. Weather-related railway disruption must be minimised to reduce socio-economic impacts, but the size, range, and geographic distribution of the railway network (i.e. the very same things that make it backbone of public transport) make this a complex task. That said, Network Rail are leading the way in embedding climate change adaptation as part of business as usual in the rail sector.

Figure 1: J.M.W. Turner's 1844 painting entitled Rain, Steam and Speed shows an early steam train crossing the recently completed Maidenhead Bridge. The original painting is now in the collection of the National Gallery, London. National Gallery file

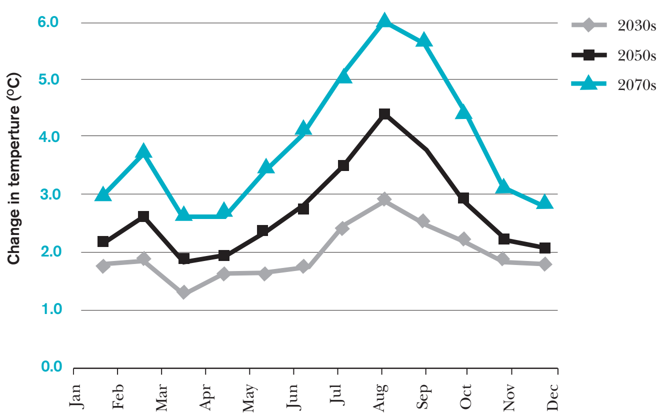

Figure 2: The change in daily maximum temperature for the West Midlands regions for 3 different time slices as determined from the RCP6.0 90th percentile. This graph forms part of the vulnerability assessment for the West Coast Mainline between London Euston and Birmingham and is taken from the Northwest and Central Route weather resilience plans 2019 – 2024 produced by Network Rail. For original data and information on Relative Concentration Pathways (RCP) see UK Climate Projections.

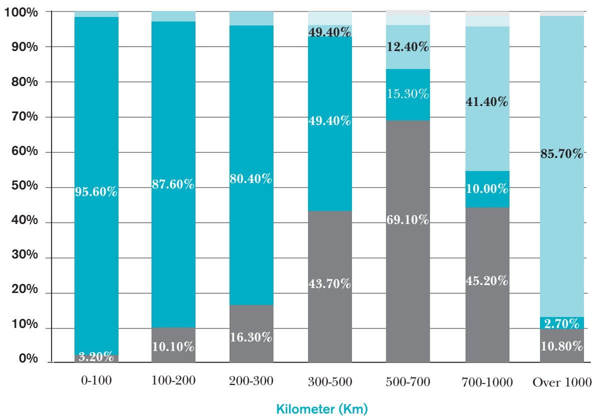

Figure 3: The delay minutes attributed to different weather types for the Northwest and Central Route that includes the West Coast Mainline between London Euston and Birmingham between 2006 and 2019. Image taken from the Northwest and Central Route weather resilience plans 2019 – 2024 produced by Network Rail.

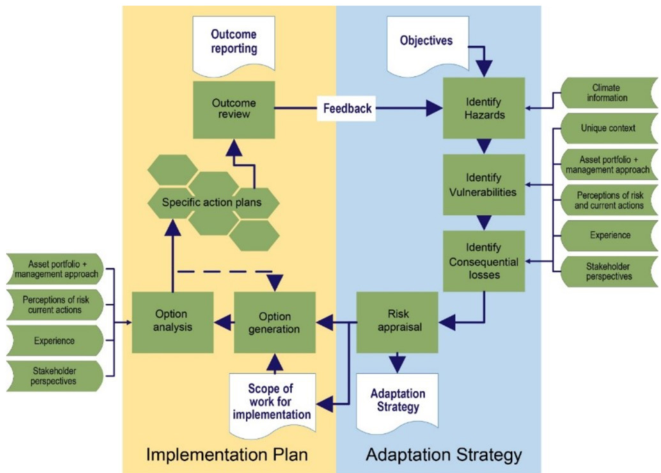

Figure 4: The Rail Adapt framework for climate change adaptation. From Quinn et al, 2019.

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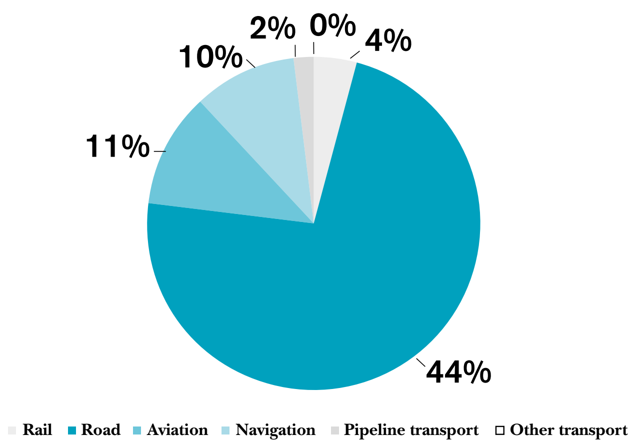
Clean transport innovation and policies: solution or trouble for climate change?

Since the Industrial Revolution, the amount of greenhouse gas emissions has risen exponentially due to the expansion of business sectors, transportation, households, and human activities – causing extreme climate change across the globe. The crisis brings with it negative social impacts such as natural disasters, animal extinctions, human ill health, and shrinking food supplies. To deal with this global warming issue, the Paris Agreement aims to limit global temperature rises to below 1.5ºC compared to pre-industrial levels. In order to minimise the impacts of climate change, various international policies have been put forward; for example, Greenpeace has long advocated for substituting coal, oil and gas with other greener and cleaner forms of energy. In addition, the UN Environmental Programme (UNEP) has been involved in global, regional and national projects aimed at tackling climate change.

According to the global CO_2 emission data, almost one-quarter of total emissions stem from the transport sectors. Transportation has become a fundamental necessity for getting to work, for leisure and so on. We see some cities taking innovative approaches to encourage people to use public transport to reduce their carbon footprint rather than using their own cars. For instance, Washington DC's regional government suggested their residents comply with car-free days in three ways: work from home or outside their regular workplaces, use public transport or ride-share.

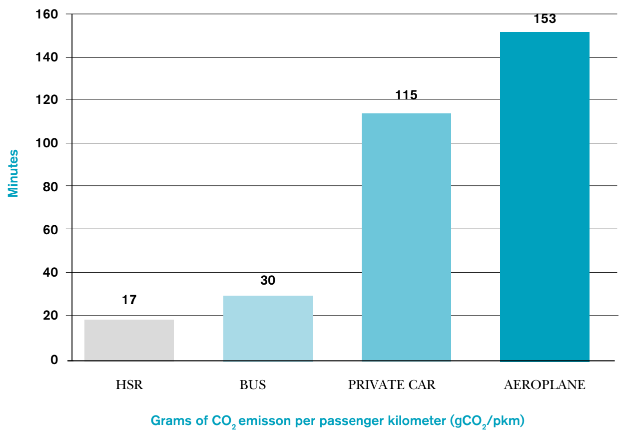
Nevertheless, the reduction in emissions from transport has become a challenging and urgent issue for researchers and engineers across all transportation sectors; with the most appropriate strategies focusing on adopting green energies and lowering CO_2 emissions.

Compared to other transportation modes, railways make a small contribution to total emissions (4.2%), whereas the emissions from roads, where most users have their own vehicle, comes in at 72.6%.



The share of CO_2 emission from each mode of transportation (Source: UIC, 2017)

The seamless and broad connection between public transportation modes has become the key enabler of mobility in developed and developing countries. Multimodal transport hubs have been built up in many countries such as China, Singapore, and the USA. These hubs aim to increase cross-mobility by generating sustainable offsets in communities where there are fewer cars, resulting in a reduction in the transport sector's carbon footprint. Some studies have compared the emission rate of each transportation mode in European countries. The findings showed that high-speed rail (HSR) has the lowest emission at 17 gCO_2 per passenger kilometre (pkm); whereas, private cars and aeroplanes emit 30 and 153 gCO_2 per pkm, respectively. This implies that HSR yields the lowest emissions, six times less than private car. However, convincing people to take HSR services instead of a private vehicle is not something that can be done quickly.



Comparison of the amount of CO_2 emissions of HSR with other modes of transportation in the EU (Source: UIC, 2017)

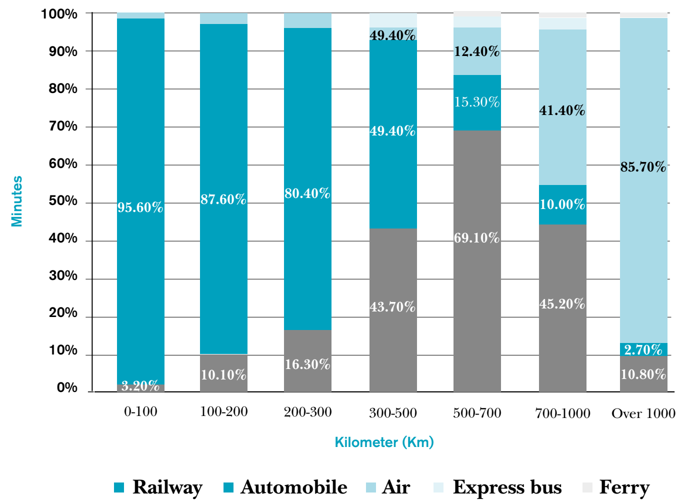
To reduce the impacts of climate change in the transport sector, we need to made advances in both policy and technology and innovation. In terms of policy, it is essential to change people's behaviour and increase their awareness about climate change. On the other hand, technology and innovation developments have been considered long-term approaches to clean transport and therefore to tackling climate change. It is now time to wind ways to accelerate their adoption.

Policy proposals

Practical measures to reduce energy consumption and use green energy sources are widely used in many countries. We propose five policies to support the development of clean transport. Firstly, all public vehicles must avoid using fossil fuel; Decarbonisation – the reduction and elimination of CO_2 emissions from fossil fuels – is now recognised globally as an essential element of tackling climate change, and the transport sector must play its part.

Secondly, the net-zero emission concept must be applied to all transport modes. The key principle of net-zero emissions is balancing the amount of carbon emissions and the amount of CO_2 in the atmosphere. Transportation sectors must discharge and remove CO_2 at equal levels using advanced technologies such as carbon capture, carbon storage, and carbon trading. Governments need to make net-zero emissions mandatory across transport sectors and work to gain public support. For example, the UK Government has set a target of achieving net-zero by 2050 – all diesel vehicles must be removed from the system by 2040 as an early tactic to reach this goal. In practice, smart planning on public transport can be a net-zero enabler. Effective transport planning should encompass the ticket price, routes and passengers' demands. A unified network that genuinely supports passengers' journeys with various routes is essential. In addition, the government must integrate all public transport on both regional and international scales. Finally, public services should offer a reasonable price to all customers. These measures will serve to steadily increase the accessibility of public transport.

A third policy measure should consider the mode of transport versus the travelling distance, since each mode has particular suitability over different operating distances. Cars have become a competitive mode for routes of less than 300 km. In contrast, trains and aeroplanes are more suitable for distances between 300 km and 1,000 km and over 1,000 km, respectively. Therefore, introducing a seamless public transit network or transportation hub to support passengers' journeys can lead to a long-term reduction in private car use, which in turn, will directly decrease CO_2 emissions.



The share of passenger transportation modes in Japan by distance (km) (Source: Kojima and et al., 2017)

Restricting private car usage and encouraging the take up of public transport seems a straightforward way to reduce emissions, but a significant change in public behaviour is required. A fourth policy approach should therefore focus on campaigns to encourage people to use public transport. In Paris, for example, the enforcement of the "odd-even licence plate" system had a significant impact on air pollution. This campaign has been used in Paris on several occasions since 1997, resulting in an significant decrease in the number of private cars on the roads. Beijing city, in China, launched a similar rule in 2008 to decrease air pollution and road traffic. Nevertheless, this method is potentially less appropriate in suburban areas that lack appropriate public transportation systems.

Lastly, a fifth policy approach would be to limit eco-unfriendly vehicles in big cities. An engaging public campaign can raise people's awareness of the impact of transport emissions, especially on air quality. According to the air quality index (AQI), most city centre and central business districts (CBD) have been encountering severe air pollution due to traffic congestion and industrial activities. Hence, the authors' suggestion is that eco-unfriendly vehicles should be banned in more polluted cities. For instance, Paris, in France, has banned all diesel vehicles made before 2006 from the city centre. This rule is applicable from 8 am to 8 pm during weekdays. Birmingham, in the UK, has implemented a permanent "Clean Air Zone" in the city centre – older vehicles which do not meet emissions standards are charged a fee to enter the restricted zone. As a result, the air quality in those regulated areas should gradually improve due to the lower emissions.

Technology and innovation development

Technology and innovation can be applied alongside our proposed policies to develop clean transport systems. Key to this is replacing the combustion engine and materials to reduce CO_2 emissions.

First, any outdated vehicle's combustion system should be replaced. Most existing vehicles are designed to support only diesel power. However, obsolete cars with a diesel engine has been banned in many cities such as Paris (France), Stuttgart (Germany), and Birmingham (UK). In other words, private and public diesel vehicles will be phased out over the next few years and their replacements will be powered by electricity or renewable energies. Various technologies and innovations have already been installed in new vehicle models that will reduce environmental impacts. For example, the Japanese N-700 series Shinkansen train is designed with a hybrid system; it supports both combustion energy and an electric motor. The new High Speed Rail model is considered a lower emitter than an aeroplane over the same travelling distance.

Second, the selection criteria for a vehicle's materials need to consider recyclability and weight. One notable material, "Carbon fibre reinforced polymer (CFRP)" is both sufficiently tough and light to be used in automotive parts such as car's bumper, car's spoiler, and railcar's bogie frame. An increase in the use of recyclable materials can decrease the amount of energy used and CO_2 emissions from all recycling stages, i.e., dismantling, shredding and cleaning processes, and also reduces waste in landfill sites. In High Speed Rail vehicles, for example, research shows that the replacement of the CFRP materials in the main parts shows a 73.1% recycling rate of total vehicle mass. Additionally, the light-weight material can decrease energy consumption, which also results in reduction of CO_2 emissions.

The application of these technologies and innovations in the transport sector could significantly reduce CO_2 emissions. Moreover, implementing them, in combination with effective transport policies, could enable the global climate change targets to be reached more swiftly. The sooner these policies are implemented, the sooner existing issues will be resolved.

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Decarbonisation and heritage railways

The UK has reduced its carbon emissions by 44% relative to levels recorded in 1990 with the transport sector acting as the largest emitter of Greenhouse Gases at 38%. Rail transport only contributes 2.5% of transport emissions, however rail must still decarbonise to achieve net-zero emissions by 2050.

Significant developments to decarbonising the rail industry include establishing a long-term rolling stock strategy to remove diesel-only trains from the GB rail network by 2040. However, for Heritage Rail where many trains are coal powered, how can they decarbonise? A simple option would be to stop steam trains from operating, but this would remove the excitement of watching a steam engine come to life and diminish the educational experiences that Heritage Rail offers. At the University of Birmingham, we are exploring the decarbonisation of Heritage Rail, introducing hydrogen fuel to existing trains without reducing their historical value. This will inform policy for decarbonisation of Heritage Rail.

Figure 1: Example of new green-marked number plate (Gov UK)

UK progress on transport emissions

The UK has recently been commended by US climate change envoy John Kerry, for its progress on addressing the climate emergency, reducing its carbon emissions by 44% relative to levels in 1990, much quicker than other wealthy nations. The UK's strategy has been to set a net-zero goal for 2050 to drive changes across all sectors to reduce emissions and decarbonise. So far much of the focus on reducing carbon emissions has been on roads, however the rise of electric vehicles will help address this, especially those that can be identified by a green-marked number plate. Cars, vans and HGVs are not an unjustified focus; the biggest contributor to UK carbon emissions is transport, and by far the biggest contributor to that is road transport.

Given that, you might wonder why we bother to look into rail decarbonisation, given that less than 2% of UK transport carbon emissions come from rail, making up just half a percent of total UK emissions. However, these numbers alone do not tell the full story; as the UK's hundreds of diesel trains churned their way through 476 million litres of diesel last year, producing other emissions including small particles, and nitrogen and sulphur oxides, as they go. Diesel trains are not only noisy, smelly and generally unpleasant but they are also harmful as particulates and other emissions are known to have a negative impact on human health. This is a particular problem in enclosed train stations such as Birmingham New Street, where levels of these airborne pollutants can be very high. If we want to encourage people to use the railways, with the consequent reduction in congestion and emissions and improvement in quality of life, we therefore have a responsibility to reduce emissions.

Decarbonising GB rail

Plans have already been made to start decarbonising the railways, such as the removal of all diesel-only trains from the national network by 2040. Significant progress has already been made, with the UK's passenger rail CO_2 emissions falling considerably over the 2010s, despite an increase in passengers.

While positive progress is being made on the mainline network, there is one area of the railway which is going to be difficult to decarbonise; heritage railways. When the main attraction of a railway is coal-burning, steam-powered trains, it would seem there is little that can be done. Of course, we could ban steam-powered trains, but this would ruin the attraction of these railways, which are important for the tourism of the communities they serve and are an important steward of social and cultural history. Various coal alternatives have been tried, with varying degrees of success, but largely they have proved unsuitable. So how could heritage rail be brought into the age of low carbon, without reducing their appeal to enthusiasts around the world? One aspect of the heritage scene that could be explored is decarbonising heritage diesel trains, for which there are a number of possible solutions.

Figure 2: Steam locomotive are often the main attraction for heritage railway (authors own collection)

Figure 3: Detail view of a partially disassembled Class 08, showing old fashioned electrical equipment (author's collection).

While it might be possible to run heritage diesel trains on biofuels, this is not as simple as it would at first appear. Firstly, these fuels are not a perfect solution; even though their production does take in carbon, they need to be transported to where they are used, and growing crops for biofuel can take up valuable land. Secondly, many older diesel engines may struggle to run well on modern biofuels, which may make this solution impractical. Another option is to replace the engine of a heritage diesel train with a system that produces fewer, or no, emissions. At first glance, this might not make sense for many diesel trains either; part of the attraction is the noise, the sights, and the sounds produced by these trains and the consequent feeling of nostalgia for by-gone times which these railways trade on.

It would be a mistake, however, to assume that all the trains on a heritage railway are there for public amusement. In order to marshall trains, move around old trains for maintenance, and keep the railway running smoothly, heritage railways require smaller locomotives called shunters. While these are often historic themselves (the most common type is the Class 08, dating from the 1950s), they are very seldom the main attraction.

What would be the options for decarbonising such a locomotive? If we were to take inspiration from the car industry, we could convert them using batteries. Although electric cars are increasingly becoming the norm, but batteries are not without their problems. The main issue is that the amount of energy that can be stored in a battery is limited and while no longer a problem for cars, trains are much bigger and heavier requiring more energy to keep going, particularly when shunting another train. In addition, the current diesel trains are expected to be in service for hours or even days at a time without refueling, and when they do refuel, this is expected to take a handful of minutes rather than the long durations typical for battery charging.

There is therefore a clear need for a technology which will provide more energy than a battery. One technology showing great promise is hydrogen, which when stored as a compressed gas, can store a lot more energy than a battery. This gas can be used in a fuel cell, which combines hydrogen with oxygen from the air. This reaction produces an electric current, which in turn can be used to drive the train. This is far more environmentally sound than a diesel engine as it produces no harmful emissions. While it is true that much hydrogen is produced from natural gas, hydrogen can also be produced by electrolysis of water; passing an electric current through it to split it into hydrogen and oxygen (an experiment many will have done in chemistry at school, albeit on a much smaller scale). If this electricity comes from renewable sources, it is possible to eliminate the use of fossil fuels entirely.

Figure 4: Hydrogen Hero at Rail Live 2020 (authors own collection).

The first University of Birmingham foray into the sphere of hydrogen-powered trains was an entry to the Institute of Mechanical Engineering's Railway Challenge, a competition for miniature locomotives entered by teams of young people. Subsequent years of the competition saw better and better entries from the University, culminating in Hydrogen Hero, which appeared not only in the competition but also at other events such as Rail Live and Modern Railways Rail Vehicles and Enhancements.

Figure 5: HydroFLEX crossing the viaduct into Evesham on a mainline test run (UoB/Porterbrook).

Further, in 2018 the University partnered with train leasing company Porterbrook to produce HydroFLEX, the UK's first full-scale hydrogen-powered train. This project involved taking an old electric train and feeding it with electricity from a hybrid system containing both a hydrogen fuel cell and a battery. As the project progressed, it brought with it considerable experience of adapting advanced hydrogen technology to a practical railway context. This experience is very much transferable to a shunter on a heritage railway as many of these old locomotives are diesel electric, meaning that they have a diesel engine which drives a generator to produce electricity for the motors driving the train. It is entirely possible to replace this diesel engine with a hydrogen fuel cell system, to produce a modern zero-emission train engine inside a heritage shunter shell. Such an approach is not without challenges. While far better than batteries, hydrogen storage still takes up a lot more room inside the locomotive than the equivalent diesel tank; this must be factored into the design.

There are numerous other difficulties to be overcome; the controls of the locomotive, normally connected to a diesel engine, must be adapted to control a hydrogen fuel cell; the radiator and cooling must be changed; and the electronics of the fuel cell system must be adjusted to feed the existing locomotive. However, none of these challenges is insurmountable, and with HydroFLEX, the University has proven itself capable of overcoming them, working alongside a multitude of partners, suppliers and the wider railway industry. The sharing of such valuable experience with partners is also an ideal opportunity for up-skilling engineers across the rail industry as the widespread introduction of hydrogen-powered trains gets closer.

The advantages for a heritage railway of a hydrogen-powered shunter go beyond the reduction in carbon emissions. Such a conversion process would take a shunter out of service for a while, which presents an opportunity to overhaul the remaining components such as brakes, and to smarten up the bodywork with a fresh lick of paint. Further, the working environment on these upgraded hydrogen locomotives or HydroShunters can be cleaned up and vastly improved over the noisy, oily environment currently encountered. In addition, the HydroShunter would be unusual and interesting, potentially bringing in more visitors, while demonstrating clean, green rail initiatives and improve the wider public perception of emissions reductions and heritage railways. Following the impact of Covid-19 on heritage lines, bringing the railways back to life with a sustainable and modern twist may well improve revenues for the ailing sector.

Figure 6: Hydroshunter: Diesel locomotive set to be converted to hydrogen power (Severn Valley Railway).

While it is still challenging to envisage the decarbonisation of coal powered engines, the conversion of behind-the-scenes locomotives like shunters can provide many benefits both for heritage rail and for the rail industry as a whole.

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Finance, business and policy

05

Climate change governance and environmental justice

When the UK Climate Change Act entered into force in 2008, the UK Government was charged with setting legal targets to reduce the emission of greenhouse gases by at least 80%, compared to a 1990 baseline, by the year 2050. Although at the time this target was seen as ambitious, it soon became clear that it would require revision to allow the UK to meet its global climate change pledges, as well as to improve the UK's performance at the national level. In its 2019 Net Zero report (p17) the Climate Change Committee recommended that rather than setting "a 97% target that leaves a small residual amount of emissions", it would be more appropriate to set a net zero target. Section 1 of the Climate Change Act was subsequently amended in 2019 to reflect a reduction of greenhouse emissions based on achieving a net zero target by 2050.

Setting a net zero target

Such a target can be achieved through a combination of the removal of existing greenhouse gases (GHGs) in the atmosphere together with a reduction of overall emissions. A net zero target is not the complete elimination of all greenhouse gases. Instead, the ultimate logic of the net zero approach is to achieve a balance between the production and removal of greenhouse gases in the atmosphere. This will be primarily achieved through various measures instituted by national governments coupled with ambitious initiatives in the private sector and wider societal changes.

One possible criticism of the net zero calculation is the reliance on technological change to deliver either emissions reductions (as with the switch to electric mobility) or to remove GHGs (for example though carbon capture and storage). Because such technology transitions take time, initial progress to the target is slow and considerable faith is placed on the capacity of future technological change to deliver decarbonisation. These technology transitions will require a variety of cross sectoral measures relating to energy generation, storage, consumption and efficiency. Moreover, a net zero target also assumes that the removal of greenhouse gases will not only be achieved through investment in technology but also by the contribution of natural carbon sinks such as forests and oceans.

In order to reach the 2050 target, the 2008 Climate Change Act put into place a trajectory for achieving climate neutrality in the form of carbon budgets whereby the Secretary of State has a duty to set an emission target every five years for each budgetary period.[1] This accommodates a gradual reduction of GHGs, recognising the point made above that some measures require time to deliver the desired reductions in carbon. Thus far, five carbon budgets have been set and the sixth carbon budget is currently being prepared. Despite the initial success in reaching the targets set in the first two budgets and being on track to meet the target set in the third budget by 2023, the UK is not on a trajectory to meet the targets set in the fourth and fifth budgets. The 3rd carbon budget (2018 to 2022) prescribed a target of 37% reduction by 2020 while the 4th carbon budget (2028 to 2032) prescribes target of 51% reduction by 2025.

Net zero policy initiatives and questions of environmental justice

If we examine the variety of sources of greenhouse gas emissions across a range of sectors, it becomes clear that there is a limit to what government can do to mandate emissions-reducing activity. Some of the most common measures that governments have put in place include the setting of emission standards and targets as well as banning

[1] Climate Change Act 2008, s (4)

certain activities or product regulation as illustrated by the phasing out of the sale of new petrol and diesel cars. Alongside such regulatory initiatives, there is room for soft law mechanisms such as partnering in voluntary schemes with private companies to reduce GHG generation, providing public information on low carbon alternatives and investing in research and development on low carbon technologies. However, technology transitions, such as the shift to electric vehicles, and their success in meeting emissions targets will require wider societal buy-in. Furthermore, these changes will have different impacts on various social groups, generating significant environmental justice implications.

Taking as an example the policy of banning the sale of new diesel and petrol cars, this ban was initially planned for 2040 but then moved forward to 2030.[2] However, the policy will permit the continuing "sale of hybrid cars and vans that can drive a significant distance with no carbon coming out of the tailpipe until 2035".[3] Assuming the continuing growth in the proportion of electricity provided from renewable sources, the switch to electric mobility offers obvious benefits in terms of reducing GHG emissions but, as electric vehicles remain relatively expensive, it passes the cost of the technology transition to the consumer (either directly for domestic transport or indirectly for commercial vehicles).

Aside from the cost of electric vehicles there are also infrastructure and energy costs, as well as further costs in the handling of end-of-life batteries which may be reflected in the overall price. Finally, we know from earlier technology transitions that consumers may lose rather than gain from such shifts. In 2008, in the European market, diesel technology was promoted as a lower carbon technology and consumers duly invested in new diesel cars only to find that concerns about urban air quality and tail pipe emissions saw the market for used diesel vehicles stall. There remains a possibility that this pattern could be replicated in relation to electric vehicles given competition from other low emission transportation technologies such as hydrogen and synthetic fuel-based systems.

Although 2030 has been chosen as the start date for the ban, as that date approaches one might expect that sales of internal combustion engine cars will fall as consumers become reluctant to invest in soon-to-be redundant technology. On the other hand, consumers may not wish to switch too early while electric vehicle technology, e.g. in terms of range and speed of re-charging, continues to improve. Nonetheless sales of electric vehicles may increase rapidly in the late 2020s creating issues of manufacturing capacity. For less wealthy consumers, who will buy vehicles from used car markets, the shift to electric vehicles may take more time. Prior to that shift, these consumers may face higher maintenance and fuel costs (as demand for petrol/diesel falls). Meanwhile such drivers of older vehicles are already facing higher motoring expenses in the form of charges to drive older vehicles in ultra-low emission zones in urban conurbations where many such consumers live and work.

Often when we focus on decarbonisation we fix on questions of sustainable production (such as energy generation) but the electric mobility illustration shows that patterns of sustainable consumption may be no less crucial. We depend on individuals' behavioural change, though such change is not cost free and will create impacts likely to generate concerns about environmental justice. So, for example, the move to net zero carbon may require significant re-investment in domestic heating, cooling and insulation systems at a time when, in England at least, the average fuel poverty gap is widening.

Environmental justice challenges

This presents Government with some considerable challenges. One immediate question is how far Government is able to develop policy which will incorporate environmental justice considerations. This has not always been the case as an example from solar power can illustrate. The take-up of domestic solar energy systems was encouraged through financial incentives, particularly through Feed in Tariffs (FiTs) which offered attractive payments for the surplus electricity produced by solar panels, when fed back into the grid. This form of subsidy was broadly more generous than other mechanisms such as the Renewable Heat Incentive, creating some feeling of unfairness. The FiTs system was withdrawn in 2019 as costs of solar investment fell and volumes of feed-in to the grid grew, but there is no doubt that early investors gained more as tariffs fell over time and early FiTs promised long-term and index-linked returns. Research into initial investments in domestic solar power systems found relatively few installations in poorer areas with a disproportionate level of investment in wealthier locations, which indicates that environmental injustices can be compounded.

A second challenge relates to mechanisms to engineer change. In late 2020, the UK Climate Change Committee suggested a 20% cut in meat and dairy by 2030, rising to 35% (for meat only) by 2050. In April 2021, when the UK Government accelerated some of its targets to reduce GHGs, the Business Secretary announced that he might turn to a vegan diet to help combat climate change. The formal position taken by Government, however, was that 'anti-meat' regulation would not be introduced. This is an understandable position from a government with distinctly libertarian instincts and the restrictions placed on everyday freedoms during the pandemic may have heightened these instincts in political circles.

2 HM Government: Ten Point Plan for a Green Industrial Revolution: Building back better, supporting green jobs, and accelerating our path to net zero, November 2020, p. 14, https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

3 Ibid p. 14.

The problem is whether in the face of a climate emergency it is really enough to shrink the role of government and put trust in autonomy in the hope that people do the right things. It seems odd to put so much emphasis on the targets yet provide such a sketchy roadmap as to how we might reach them. Moreover, the setting of top down targets risks a lack of buy-in or even a democratic deficit, given the sizable changes that the targets imply and their potential disproportionate impact on certain groups. This is not to decry target-setting but rather to point to the necessity for inclusive and participative decision-making on how these targets can be met.

Finally, it is worth remembering that climate change is an environmental justice issue both globally and locally. At a global level it is a cruel irony that may countries that have made much lower contributions to GHG emissions will suffer most under its impacts. At the Copenhagen Climate Change Conference in 2009, developed countries pledged $100 billion per year by 2020 to help developing nations adapt to the impacts of climate change. Unfortunately, accounting mechanisms to assess this were never put in place but it appears not to have been met even with the most generous metrics. So, in financing domestic transitions, this global commitment should not be lost.

In terms of domestic victims of climate impacts – such as those flooded out of homes or overtaken by sea level rise – whose ruinous situation is not of their making, the appeal must be for communal engagement with climate change mitigation and adaptation to the greater benefit of all. It would be great if we were able to trust voluntary individual action but the reality is that immediate and dependable legal mechanisms are needed to promote climate change mitigation and adaptation. Setting targets should not be mistaken for action representing, as it does, the easiest possible form of political intervention. Devising governance solutions to deliver those targets in a manner which is conscious and respectful of environmental justice is a much more exacting test of political leadership.

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Moving towards a sustainable planet: what is the role of financial markets?

Why climate finance?

Recent episodes of environmental disasters such as wildfires, typhoons and droughts provide evidence of the catastrophic economic impact of climate change. These events have a devastating impact on infrastructure, natural habitats and have inflicted suffering on our collective wellbeing. The climate crisis is therefore an immediate existential threat. The former Bank of England governor and the UN envoy for climate action and finance, Mark Carney, has warned that the climate crisis potential death toll could, by far, exceed the Covid-19 pandemic. The estimated annual cost of natural disasters caused by climate change is about $18 billion in low and middle-income countries and $390 billion to companies and households worldwide.

The extensive burning of fossil fuels is the primary source of greenhouse gases emissions. Transportation, electricity production, and manufacturing sectors accounts for the larger proportion of emissions that traps the heat in the atmosphere and causes global warming. Global warming, in turn, has led to even greater demand on energy; the world energy consumption in 2019 was roughly 584 exa-Joule (this is equivalent to powering 27 light bulbs of 50W each for 13.8 billion years). This, indeed, has implications for financial sector to fund the transition to greener economies to combat the impact of global warming. Figure 1 presents the CO_2 emission in 2019; the top 4 emitters account for 56% of CO_2 emission while the rest of the world account for 44%.

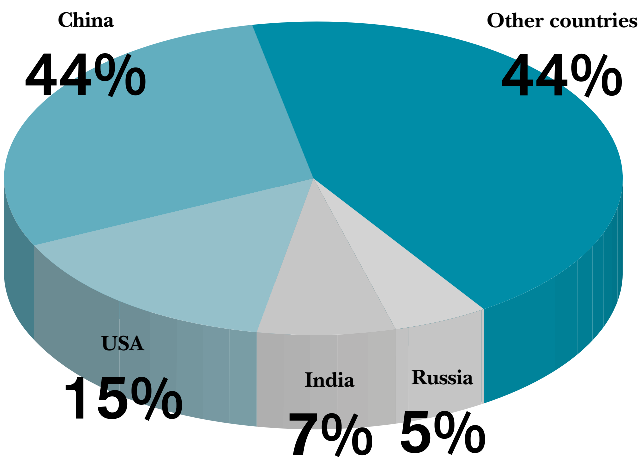

Figure 1: Mt CO_2 emission in 2019
Source: Global Carbon Project

Recognising the important role of the financial sector in combatting climate change, HM Treasury and the Department for Business, Energy & Industrial Strategy, in 2019, published the UK Green Finance Strategy. This aims at greening financial systems by focussing financial market attention on investments that contribute to a major transformation to clean and resilient economic growth. The Green Finance Institute (GFI) was created as part of this policy initiative with a remit to achieve an inclusive, net-zero carbon and resilient economy.

To bridge the funding gap, financial markets are moving in a positive direction to deliver sustainable greener economies. Funding the transition to sustainable low-carbon economies is a challenge that needs solidarity from the international community. Climate Finance is therefore an important part of the international drive to achieve a solution to the problem of Climate Change.

Financial institutions worldwide, prompted by their own risk assessments, by investors, as well as by Regulators, are developing innovative sources of finance that have led to the rise of "Climate Finance"; The UNFCCC defines climate finance as "local, national or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change". Figure 2 shows that the annual climate finance flows exceeded USD half-trillion mark for the first time in 2018 and clearly will grow further over the coming decade to meet the global environmental challenges.

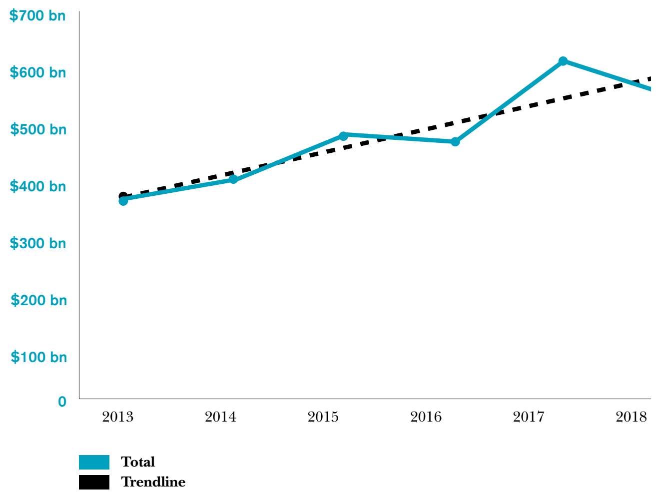

Figure 2: Total Global Climate Finance Flows 2013-2018
Source: Climate Policy Initiative

However, this is a drop in the ocean compared with the funding provided to fossil fuel-based projects. During the five years, post Paris Accord, the top 60 banks worldwide poured $3.8 trillion into fossil fuels-based projects. Figure 3 presents the top 15 banks financing fossil fuels projects globally, 2016 – 2020.

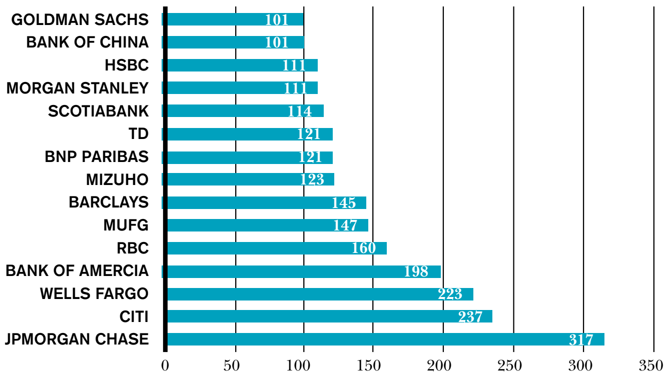

Figure 3: Top 15 banks financing fossil fuels globally, 2016 – 2020 (US Billions)
Source: Banking on Climate Chaos Report, 2021

The challenges facing the global economy are clear from these relative funding figures and the changes in production and consumption that are required are similarly huge. Financial markets and institutions will need to develop green finance as a matter of urgency in order to provide the finance required to deliver the necessary shift to a green economy. Therefore, financial innovation is bound to be a key mechanism for delivering sustainable economic structures.

Innovation in financial markets

Financial innovation has the power to significantly change the landscape of finance available for businesses. The creation of Green, Blue and Social/Sustainability Bonds is one example of financial innovation that has delivered funding to support the response to climate change. The proceeds of Green Bonds are committed to finance climate friendly projects while the proceeds of Blue Bonds are devoted to fund sustainable marine and ocean-based initiatives. These innovations are non-mutually exclusive types; for instance, Social Bonds could be common ordinary Bonds but with proceeds directed to environmentally friendly projects. The cumulative market value of Green Bonds issuance to date is US$1.185tn. In 2019, Fannie Mae - the US Federal National Mortgage Association – issued the largest amount of Green Mortgage Backed Securities (US$22.8bn). And HSBC has recently announced their global commitment to provide $100 billion in sustainable financing and investment by 2025. Figures 4 and 5 present the quarterly global Green and Sustainability Bonds issuance up to the third quarter of 2020.

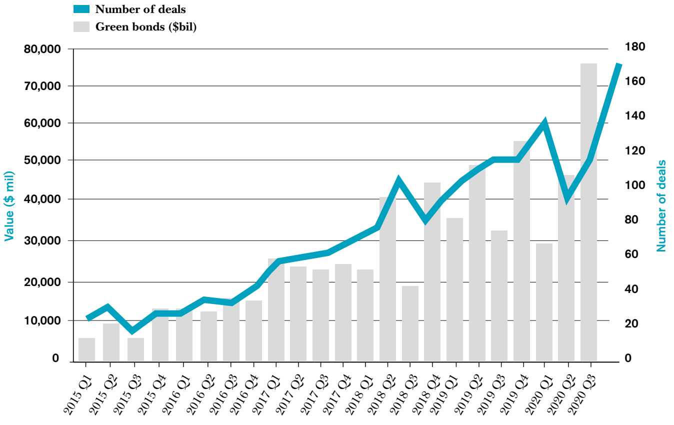

Figure 4: Quarterly Global Green Bonds
Source: Refinitiv Deals Intelligence

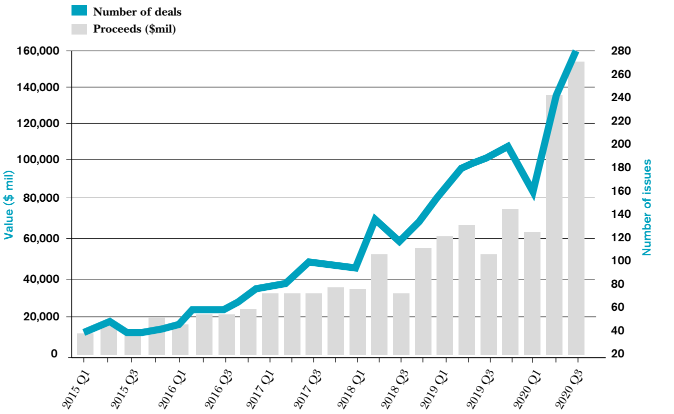

Figure 5: Sustainable Bonds Quarterly Volumes
Source: Refinitiv Deals Intelligence

But there is much more to do in terms of financial markets development, instruments, and regulations to achieve the required switch to green investing. In the wake of its commitments to reach net zero carbon emissions by 2050, the UK is the first country to set out plans to issue the first ever Sovereign Green Bond while the Republic of Seychelles was first to issue sovereign Blue Bonds worth US$15 million in October 2018. Morgan Stanley, in collaboration with the World Bank, issued $10 million worth of Blue Bonds to clear plastic pollution in the ocean and The Nature Conservancy announced an ambitious plan to issue $1.6 billion worth of Blue Bonds by 2025. More funding will be required in the wake of the Japanese government's recent decision to release 1.23 million tons of radioactive contaminated water from the Fukushima nuclear plant into the Pacific Ocean.

Green or Blue Bonds issuance sends a strong positive signal to stakeholders on a company's commitments towards undertaking environmentally friendly projects. However, companies may issue such innovative Bonds to improve their image "greenwashing" or to benefit from the use of cheaper finance. A recent study finds that the two main motivations for investors to hold socially responsible mutual funds are social preferences and social signalling and that financial motives are not the main driver for socially responsible investments (SRI) decisions.

Financial markets implications

Beyond the creation of new financial products, uncertainty about the economic impact of climate change, pricing and hedging for climate risk, further complicates the estimation of risk premia and the overall social cost of climate change. It is becoming clear that carbon emission has implications for stock markets; a recent study finds that higher carbon emission leads to lower valuation of US companies. Another study found evidence of "carbon exposure premium" as the required rate of return for companies with high carbon emission exceeds those with lower emission. Carbon Pricing is a key policy followed by 46 national jurisdictions – as of November, 2019 – to address climate change. Such initiatives will have an impact on the cost of capital and companies with high levels of carbon emission will have lower market values consequently.

However, the imposition of carbon taxes could have unintended consequences for the energy sector, such as fossil fuel stranded assets. Climate risks, in particular regulatory risk, also have implications for portfolio construction and asset allocations. Fund managers, as a result of increasing pressure from stakeholders, incorporate Environment, Social and Governance (ESG) criteria into their portfolios. A study found that incorporating ESG criteria into investment decision could reduce portfolio risk.

The economic implications of climate change have been investigated in fixed income securities markets. For instance, Green Bonds are found to offer, on average, lower yields (since they are issued at a premium). However, a recent study investigated whether investors are willing to sacrifice higher yields for societal benefits and found no difference in the pricing of Green and non-Green bonds; this implies that the greenium is zero. This result varies across countries as those impacted by climate change are expected to pay higher underwriting fees and higher premiums on long-term municipal bonds reflecting the higher risks associated with climate change that they face. Overall, stock markets are found to react positively to the issuance of Green Bonds.

Climate change also has implications for the real estate sector; sea level rise and flooding riskea level rise and flooding risk are obvious examples that have clear economic impact, for example the impact of Hurricane Sandy in 2012 on property prices in New York City. The long-term impact of climate risk has been investigated. A study found that by the year 2100 around 13.1 million Americans will be impacted if the sea level rises by 1.8 metres; another study estimates that about 1.9 million houses worth of $882 billion, mainly in Florida, will be at risk of flooding if the sea level rises by six feet. A recent study found that houses exposed to rising sea levels are sold on average 7% less than unexposed properties. Awareness of global warming is increasing;

a study found that where local temperatures are abnormally high, the volume of Google searches for "global warming" is increasing across different cities around the world.

Hedging against climate risk is a key challenge for financial markets as the existing derivatives instruments and specialised insurance products typically do not cover the long-term impact of climate risk. A recent study designed an alternative approach to hedge against climate risk by designing a "climate news" index using the WSJ coverage of climate change news. While, climate-resilient assets will continue their growth, empirical research will need to inform decision-makers and regulatory bodies about improved measures of companies' climate risk. This will spur financial innovation to develop appropriate techniques for hedging against climate risk, the social cost of carbon emissions, and the impact of climate risk on financial stability.

Disclosure and shareholder activism

Although, voluntary disclosure is an essential step towards greater transparency on climate risks, a policy intervention is required to make such disclosure mandatory. The UK is the first country to establish a Task Force on Climate-related Financial Disclosures (TCFD) which aims to make disclosures fully mandatory across the economy by 2025, going beyond the 'comply or explain' approach. While the US Securities and Exchange Commission (SEC) regularly assesses how current climate change disclosures adequately inform investors, the U.S. climate envoy, John Kerry, recently highlighted that President Biden is set to issue an executive order on climate disclosure in capital markets.

Since financial markets are global there has been a push towards standardisation of regulation and supervision. The British Standard Institute (BSI) has developed a set of standards for financial institutions to align with the global sustainability challenges and to promote the UK Green Finance strategy. The Climate Bonds Initiative (CBI) published its Climate Bonds Standard and Certification Scheme in 2010 and the International Capital Markets Association (ICMA), introduced the principles of green loans in 2014 as voluntary initiatives.

Stakeholders also play a fundamental role in shaping corporate culture and raising awareness of the ESG and SRI investing; the United Nations-backed Principles of Responsible Investments (PRI) and the promote the importance of incorporating environmental, social and corporate governance issues into investment practices. ESG assets under management have a value of around US$40.5 trillion, which is equivalent to one third of all professionally managed assets. Shareholder activists continue to put pressure on boards to undertake voluntary disclosure of the potential impact of climate change and its risk mitigation measures. A recent study found that shareholder activists play an essential role in influencing companies to disclose climate change risks voluntarily. The study also found that stock markets react positively to climate-related disclosure. Shareholders of BP, Exxon Mobil, Occidental Petroleum, and PPL Corporation agreed proposals to disclose on the risks of climate change. However, recently, the board of Berkshire Hathaway unanimously recommended shareholders vote against a proposal to disclose the company's climate risk management approach.

There is a large strand of literature that considers how to align directors' interests with wider stakeholder interests to combat the impact of climate change. In 2009, the Business Roundtable in the US redefined the purpose of corporations in a statement signed by 181 CEOs that required them to commit to lead their companies for the benefit of all stakeholders. A recent study found that aligning executive compensation to ESG criteria leads to an increase in social and environmental initiatives. Another study found that 51% of S&P 500 companies incorporate ESG metrics (mostly subjective) in their incentive plans. In the UK, 45% of FTSE100 companies incorporate ESG measures into their executive incentive plans.

Concluding remarks

Although, most countries have committed to reach net zero carbon emissions by 2050, the current political landscape and the impact of the Covid-19 pandemic could influence implementation plans. Recently, the UK, EU and the US have committed to a substantial cut (50% - 68%) in carbon emissions by 2030. However, India as one of the top carbon emitters see the 2050 net zero target as a "pie in the sky". This could lead to "free riding problems"; a recent study argued that countries that are not taking serious measures towards reducing greenhouse gas emissions will benefit if other countries do reduce their emissions. The study emphasises the need to establish a governing body with clear responsibility to ensure all countries deliver on their climate commitments.

The rapid growth in financial technology casts doubt on achieving the net-zero carbon by some countries. The world electricity consumption for Bitcoin in 2019 was 126.07 terawatt-hours (TWh). This is higher than the total energy consumption in Norway (124.13 TWh per year) or Argentina (125.03 TWh per year). A recent study reported that, in April 2020, 75% of the world's cryptocurrencies mining is found in China and that the growth in crypto assets and blockchain activities is expected to generate 130.50 million metric tons of carbon emissions by 2024.

While Sustainable Finance will continue its growth, academics and practitioners are facing challenges to set out a new research agenda including important policy questions about risk and return profiles and premiums (the greenium) of green financial assets particularly in the context that the risks associated with climate change are very long term. In addition, there are questions to be answered about the objectives of investors who hold green assets. For instance, why do investors sacrifice a reasonably high rate of return on conventional bonds and invest in a lower rate of return on sustainable bonds? Disclosure on climate risks also presents different perspectives in the context of market reaction; the results of academic research reveal that voluntary disclosure leads to a positive stock market reaction as investors value transparency. Regulatory bodies are often required to continue to raise the disclosure bar until mandatory disclosure is in place. Further research is needed to understand the costs and benefits of regulation in respect to climate change. For example, there are unintended consequences of addressing climate change risks. In Jan 2021 the market value of energy companies listed on S&P500 dropped by 12% compared with market value in Jan 2020. The growth in sustainability-based investments, together with divestment campaigns by stakeholders, has led some fund managers to screen out polluting companies from their portfolios. This may be welcomed as a market response to climate risk, but it is unclear what the long-term impact of such market moves will be. Given that the market capitalisation of the biggest ten energy companies worldwide by the end of 2020 was about US$2.2trilion, it could lead to a substantial stranded assets risk and a potential systemic risk.

We conclude with a set of recommendations for policy debate. First, company boards should think strategically about their wider stakeholders and align shareholder value with stakeholder value. Second, regulatory changes should be made to tax negative externalities and to raise the disclosure bar leading to a mandatory disclosure on climate related risk and its mitigation measures, and to design an international mechanism by which a fair climate finance contribution by top emitters is achieved. Third, international collaboration should be established to accelerate the transitions towards clean energy and to put measures in place to mitigate any unintended consequences of that transition. Fourth, there should be a clear strategy from financial institutions and markets to develop financial products and institutions that can assist in the process of moving to a sustainable economy. This includes the creation of financial assets that fund the real sector developments that will stop global warming and, more generally, prevent damage to the environment. Finally, we should recognise that economies and financial sectors may need to move at different speeds and the role of international agencies in achieving a balance across developed and developing economies is important in this regard.

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The business of environmental protection

Environmental degradation is a challenge for scientists, to understand the causes, consequences and potential solutions, and for economists, to ensure that the behaviours of firms and households evolve to reflect and account for the true costs of environmental damage. The UoB-Nankai Joint Research Institute for Green Growth addresses the dichotomy of economic growth under the market system and environmental protection, which has at its heart the Precautionary Principle. Our premise is that operationalising benign by design production, a technology driven focus on emissions reduction and a social movement around green growth, underpinned by solid environmental and industrial economic principles, will lead to a framework for green economic growth. Delivering this requires innovative integration of technological, regulatory and financial incentives for businesses into economic and environmental policy, and significant lifestyle changes for individuals to value environmental protection.

Pollution is the great challenge of the Anthropocene epoch, contributing to reduced health and wellbeing, driving climate change, biodiversity loss, ocean acidification, and harming the world's fresh water supply. The Lancet Commission on Pollution and Health demonstrated that pollution is responsible for 9 million premature deaths each year. However, pollution is both preventable and recoverable with investment and innovation, and thus there is a clear need to develop the business model for green growth or the "business of environmental protection". To achieve continued economic prosperity within the sustainable resources of the planet, the global economy needs to deliver growth that reflects the true cost of that growth. If that is not achieved resources (including the environment) are inefficiently allocated. A well-known way of describing these trends is the Green Economy, which involves large scale, dramatic changes in the way the global economy operates and countries interact to become low carbon, resource efficient and socially inclusive.

While it is difficult to quantify the current value and scale of the green economy, several approaches are emerging. Early efforts by the UK government to define 'Environmental Technologies' in 2007 were a response to the limitations of the UK industry classification system to accurately estimate the economic value of environmental protection within the UK economy. Building on this, the Low Carbon and Environmental Goods and Services Sector (LCEGSS) dataset has been developed using a wide range of data types and sources, and a sectoral definition that is both 'top-down' and 'bottom-up' and was defined to reflect efforts to better align the environmental protection, renewable energy and resources management sections of the definition with Eurostat's Environmental Goods and Services Sectors (EGSS). Table 1 shows the first two levels of the main LCEGSS taxonomy, with the third level available in the full dataset.

Level 1	Level 2
Environmental	Air pollution Bio-diversity Contaminated land reclamation and remediation Energy from waste Environmental consultancy and related services Environmental monitoring, instrumental and analysis Marine pollution control Noise and vibration control Recovery and recycling Waste management Water supply and waste water treatment
Low Carbon	Additional energy sources Alternative fuel vehicle Alternative fuels Building technologies Carbon capture and storage Carbon finance Energy management Nuclear power
Renewable Energy	Biomass Geothermal Hydro Photovoltaic Renewable energy general consultancy Wave and tidal Wind

Table 1: The first two levels of the taxonomy developed to categorise and value the global Low Carbon and Environmental Goods and Services Sector. From Georgeson & Maslin, 2019).

Within the UK green economy, Low Carbon is the largest Level 1 sub-sector and grew 6.9% (sales) between 2014/15 and 2015/16, with sales of £3,572 million and 1,172 companies employing 22,888 people. Renewable Energy was the second largest Level 1 sub-sector and also grew 6.9% (sales) in the same period, with sales amounting to £1,956 million across 846 companies employing 14,645 people. Environmental is the smallest Level 1 sub-sector and grew just 3.5% (Sales) in the period, leading to sales of £1,231 million by 380 companies employing 7,583 people. Despite this, the Committee on Climate Change has highlighted both heat and transport as energy demand markets in which the UK is failing to make sufficient headway to reduce reliance on fossil fuels, e.g., only 1.2% of car sales in 2016 were electric cars but by 2030 three out of every five new cars sold (60%) need to be electric, and the trajectory for reduction in emissions from transport is falling quite a long way short of ambitions (-17%).

A key driver of many of the preventable and recoverable pollution processes globally, and a clear focus for potential environmental solutions, are particles be they natural, anthropogenic or engineered. Many particles are harmful to human and environmental health, such as the well-known PM10 and PM2.5 air pollution particles and their smaller ultrafine fraction, which are are linked with respiratory and cardiovascular diseases, as well as neurodegeneration and cancer, with air pollution linked to 40,000 deaths/year in the UK and responsible for reducing UK life expectancy by 4-6 months. Nearly 300 cities in China badly failed air-quality standard measurements in 2015, according to data collected by Greenpeace, and more than 1.6 million people per year die in China from breathing toxic air.

Air pollution alone has been estimated to reduce GDP by 6.5 percent annually, according to RAND Corp. estimates, mainly driven by lost productivity, since factories are shut down on bad air days to avoid the dangerous health effects of breathing the dense, toxic air. The visibility of air pollution means that it makes headlines, but water and soil pollution are equally harmful. Water pollution is exacerbating China's severe water scarcity problems, bringing the overall cost of water scarcity to about 1% of GDP.

Another aspect of particles is their capability of transporting other species such as viruses and infectious agents, and indeed the correlation between air pollution hotspots and Covid hotspots is clear, although the underlying mechanisms and whether viruses associated with PM remain infectious is still being investigated. Road deposited dust particles have also been associated with the transport of other pollutants including metals and phosphorus, continuing the re-distribution of pollutants between air and water. Because of their particulate nature and tendency to aggregate, particles are useful targets for pollution remediation themselves as they can be "trapped or caught", and as a result of their high surface area for binding of co-pollutants facilitating the capture and remediation of target pollutants. Thus, much of the scientific and technological focus of both reduction and mitigation of pollution focusses around particle-based solutions, and as this is a core expertise area in both UoB and Nankai particle-driven solutions were selected as one of the key foci for the scientific and technological stands of the UoB-Nankai Joint Institute for Green Growth. Research areas span sensor development, evaluation of the health and safety of advanced materials, developed of strategies to reduce air pollution, and development of particles that are safe and sustainable by design such as utilising low carbon source materials, greener synthesis approaches, or considering recovery and re-use of constituent components at the design stage, so called benign-by-design production. A clear focus on design of solutions that are cheap, can be retrofitted easily onto existing industrial plants and result in demonstrable improvements to environmental quality is central to the Institute's activities.

Benign by design (BbD) production and development means that considerations of the environment happen much earlier in the product/process development approach. At the heart of BbD lies the concept of substituting the question "Is it safe/sustainable?" with "Can we engineer it to be safe/ sustainable?" These concepts reflect the need to reduce reliance on critical non-renewable resources and to move away from the single-use culture towards a more circular economy. Coupling this approach with technologies for emissions reduction across a product/process life cycle will result in dramatically greener production approaches and lower environmental pollution and damage. However, technical solutions alone are not sufficient to address the problems, and thus the core aspect of the UoB-Nankai Joint Research Institute for Green Growth is the *interweaving of a technological and economic focus*, including development of a set of tools and interventions to support the integration of environmental factors enter into business decision making and behaviour, including providing important multi-stakeholder perspectives, and leading to co-development of new approaches to drive green growth. The foreseen output is the development of the reference framework, including policy, economic and technological instruments that can be applied in the balancing of economic (growth) with environmental (sustainable and pollution reduction) needs, utilisable by the Chinese and British authorities to make economic and environmental policy decisions.

The interweaving of a technological (emissions reduction and remediation focused environmental science) and economic focus, directed through a deepened understanding of both consumer and business attitudes to environmental policy, as shown schematically in Figure 1, will lead to improvements on three fronts:

(1) a social movement on public health benefits derived from a clean environment,
(2) an industrial focus on cost-effective emissions reduction coupled to corporate responsibility and sustainability as selling points, and
(3) a governmental policy framework that maximises incentives for green growth and provides a roadmap and toolbox of policy interventions to address specific local, regional and national environmental and economic challenges.

Key activities include efforts to engage the wider community in public debate around who should fund the costs associated with remediation and public health projects such as reduction of emissions. Development of public-private partnerships to address these issues will be a central focus of the "green growth: the business of environmental protection" framework.

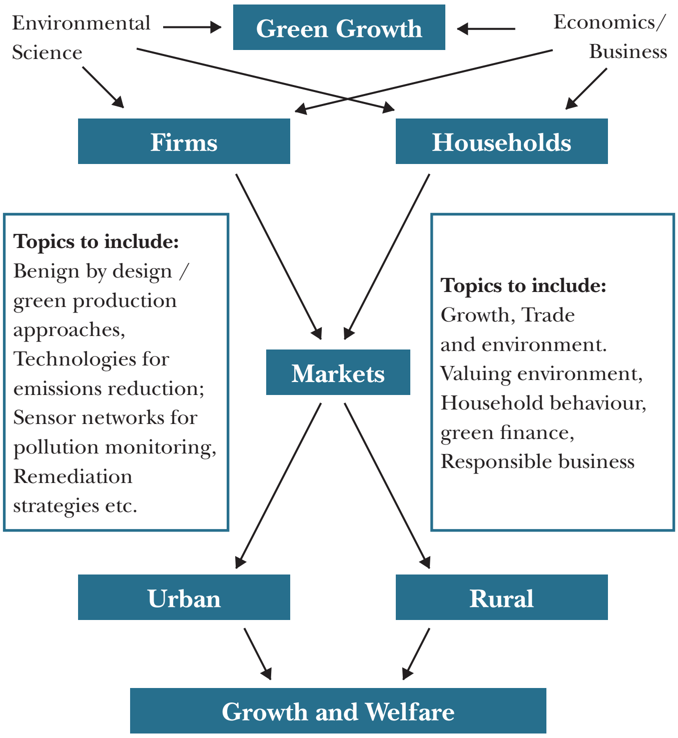

Figure 1: Schematic illustration of the broader approach to integrating Environmental Science and Economics/Business to provide workable solutions to the growing environmental problems of developing countries. The framework is being exemplified initially by China, and subsequently being translated and adapted to the needs of other Asian and African economies.

Our working hypothesis is that identifying how the scientific discoveries and innovations which will solve environmental challenges can influence the behaviour of firms, households and markets will ensure that the true cost of environmental degradation is understood and that economies respond by the right sort of innovation and response to scientific understanding and hence to allocating resources efficiently. For example, residents' consumer preferences (physical health, living environment, environment-friendly products or services) and further impact their behaviour (willingness to pay for environment, consumption demand, choice of employment and residence, participation in public policy making, active recycling efforts, etc.). The impact of environmental regulation upon corporate performance and corporate behaviour (consumption demand, market share, cost, industry access requirement (consumers, industry access, location, innovation and corporate restructuring, etc.), use of technologies to reduce emissions, sustainability practices etc.) in developed (UK) versus rapidly developing (China) will lay the foundation for industrial analysis and macroeconomic analysis. This is being supplemented with field work in key areas including rural-urban gradients to evaluate the air, water and soil quality in Beijing, Tianjin, Hebei, Huaihe River Basin and other key areas, through collaboration with the environmental protection authorities, in order to lay down mid-term and long-term evolutionary path and respective policy framework and technology interventions for environmental remediation and long-term reduction in emissions.

The dual challenge of growing populations and rapid urbanisation have resulted in enormous challenges to the planet's ecosystems and the essential life-giving services they provide, including access to clean water, air and food. Facilitating the economic transformation and growth of global south countries whilst maintaining or improving the environmental footprints of rapidly developing economies – i.e., developing a framework for Green Growth and envisioning environmental protection as a profitable business enterprise in itself via the Business of Environmental Protection - is a vital and multi-dimensional challenge that will be tackled by the UoB-Nankai Joint Institute of Green Growth through the unique pairing of environmental sciences, economists, social change actors and a variety of public, municipal and industrial leaders. Indeed, the dual role of environmental sciences and economics have been visualised very effectively by UN Economic Commission for Europe's mapping of the environmental relevance to the 17 Sustainable Development Goals, with 8 being found to have a strong link, 3 a moderate link and just 6 having a limited environmental aspect, as shown in Figure 2.

Figure 2: Mapping of the SDGs in terms of their environmental relevance and activities undertaken by the Environment subprogramme of the United Nations Economic Commission for Europe.

In summary, we need to find ways of developing the global economy without environmental degradation. This means incorporating the value of nature into our economic strategies and placing environmental protection at the heart of all developments. Unravelling this complex issue requires a multi-disciplinary approach, bringing together people with a wide range of expertise.

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Behaviourally informed climate change policies

While greenhouse gas (GhG) emissions have been falling across many industrialised nations – for instance, GhG emissions in the UK are now 43.8% below their 1990 level – more substantive emission reductions are needed to stabilise the global climate at 1.5 or 2 degrees of warming. This reduction is becoming even more critical since falling emission in industrialised nations have been offset by rising emissions in quickly industrialising nations. By some estimates, global carbon emissions would need to fall by 7.6% each year for the next decade if the goal of restricting warming to 1.5 degrees is still to be met.

Decarbonising the economy requires changes in how we produce energy and food, how we travel and how we heat our homes and manage our cities. There are at least two fundamental reasons why relying on voluntary changes in consumer behaviour alone will not be enough to bring forth these radical changes.

The first reason is technology. Even with the restrictions on personal freedoms and economic activities put in place during Covid-19 lockdowns, global GhG emissions have "only" fallen by 6.4% in 2020 - with more considerable reductions seen in some countries like the US (12.9%) and EU (7.7%). The economic costs of lockdown measures have been in the trillions, and the support for them has been continuously weakening as a result. Further emission reductions will only find broad support in the population if they are economically less painful. We need more technologies that break the link between consumption and emissions. While there is more optimism now, with several industrialised countries recently displaying decoupling of GDP from both production- and to a lower degree from consumption-based CO_2 emissions, it is still unclear whether decoupling can happen fast enough. A central question for climate policies for the coming decades is therefore how the development of such technologies and their diffusion can be sped up. Policies that directly support R&D for clean technologies could supplement other policies that support the diffusion of cleaner technologies through taxes and subsidies.

The second reasons why voluntary changes in consumer behaviour will not be sufficient is engrained in the word "voluntary". Climate change is a global problem that affects billions of people, most of whom are not even born yet. A single consumer completely changing their consumption habits today would still have a minuscule impact on preventing future climate change if acting in isolation. The collective action of all consumers is required in this global cooperation problem. Our own research shows that the psychological mechanisms that typically support cooperation in small groups, such as punishing free-riders, are not well suited for a setting where groups are large and benefits mostly flow to those living in the future. It is therefore not surprising that the mean willingness to pay (WTP) for voluntary carbon reductions of 1 ton (which is about what the typical European emits in 6-8 weeks) found in incentivised settings is as low as $6. This WTP is far below even more conservative estimates of the social cost of carbon (SCC) which expect the economic cost of emitting an additional ton of CO_2 now at around $30. Other estimates for the SCC come to much higher values ranging from $55 to $90 today and $286-$1700 in 2100. In sum, voluntary climate actions are far from enough to reach an emissions trajectory that keeps global warming within the limits set by the Paris Agreement.

Policymakers have long recognised the need for more stringent policies, and pricing carbon emissions through the tax system is becoming more common in many industrialised countries. The idea is simple – by attaching the same price to all emissions, carbon-intensive activities will become relatively more expensive. Increased costs provide an incentive to both firms and consumers to replace carbon-intensive, and therefore more costly, activities with alternatives that are cheaper and lead to lower emissions. A carbon price also helps consumers and firms quickly identify climate-friendly actions; complex information about the carbon content of single products or production process is boiled down to a simple price metric that decision-makers are typically familiar with.

It is not surprising that a panel of leading economists sees pricing emissions almost unanimously as the best and cheapest way of achieving additional emission reductions. However, this broad support for carbon taxes is not shared by the general population. For instance, while 65% of US citizens support more decisive efforts to combat climate change, only 35% support increasing the gasoline tax by 25ct per litre.

There are at least two reasons for the low support for carbon taxes.

First, some of those concerned about climate change are not convinced about the effectiveness of a carbon tax. At the heart of this concern is the misperception that taxes are merely a means of generating government revenue, ignoring the incentive effects that taxes typically have. This concern is not entirely unfounded. The price elasticity (i.e., the extent to which consumers react to a price change) can be indeed low for some relevant goods. For instance, some estimates suggest that a 10% increase in price only leads to a 1% reduction in demand for fuel. However, not all carbon-intensive goods are that price inelastic. For producers, there is even more compelling evidence that carbon taxes are not only effective but more effective than their alternatives. A comparison of clean energy subsidies in Germany and carbon pricing in the UK reveals that the latter approach has led to a 55% drop in emissions from energy production within five years. The former approach has led to much more modest emission reductions. However, one could still argue that subsidies in Germany have accelerated research into renewables considerably.

In sum, policymakers need to provide a more straightforward message about how effective environmental taxation can be. This message can be supported with several additional policies. Although irrelevant to the incentive argument, earmarking some of the tax revenue for environmental purposes has proven to be an effective strategy that convinces those who doubt the usefulness of environmental taxes. Those concerned about climate change may also worry that applying environmental taxes at the national level is ineffective as the resulting emissions reduction will be offset by higher emissions in other countries with lower taxes resulting from the relocation of polluting industries to less regulated countries. Besides the fact that these so-called “pollution haven” effects are weaker than one would expect in theory, introducing border tax adjustments – such as the one recently discussed by the EU – on carbon emissions may further calm such fears. Another strategy would be to stress the local co-benefits of reducing carbon emissions. Reducing carbon emissions by phasing out coal or reducing inner-city traffic often have local benefits such as improved air quality and shorter commute times. Stressing such co-benefits could be helpful in two respects. First, compared to the benefits of cutting carbon emissions, they are felt immediately. Second, they help local communities. Our own research shows that individuals care about the location where public goods are provided even when they do not personally benefit from them.

A second reason for citizens to be sceptical of carbon pricing is that they do not only overestimate their own burden of environmental taxes, but they also rightly anticipate that carbon taxes are often regressive. For instance, the Institute of Fiscal Studies finds that an increase in the UK fuel duty of 5% would impact the bottom 10% of income earners most. Behavioural economists have amassed a large body of evidence highlighting people’s aversion to inequalities such as this. Carbon pricing would therefore be best accompanied by redistributive measures to increase their acceptability. There are multiple policy proposals of how a more even distribution of the burden of climate policies can be achieved at the national level. Taxing carbon or auctioning off emission permits leads to additional government revenue. This revenue can be redistributed directly to lower-income households via a carbon dividend, or other distortionary taxes, such as income tax, can be lowered in a revenue-neutral way.

In addition to carbon pricing, several behavioural interventions could be used to “nudge” consumers towards more sustainable lifestyles. The first idea would be to recognise that we all suffer from status-quo bias. People tend to have an inherent preference for the current state of affairs, translating into opposition to any political reforms. Especially when thinking about local implementations of carbon pricing, such as clean air zones or congestion pricing, trial periods and low initial tax rates could overcome status-quo effects. Another area that appears promising is digging into the power of social norms. Our research shows that individuals are more willing to contribute to voluntary climate actions if they believe that others contribute as well. A typical application of these insights is in household energy use. Many power providers now inform their customers how their energy consumption compares to that of their neighbours. Such information is especially impactful on those households that consume far more energy than the average household. A final area where behavioural interventions may complement carbon pricing is information. Not only are consumers sometimes inattentive to price changes, poorly informed about energy efficiency standards or biased in their information uptake, but they may be also deterred from selecting into government subsidy programs if the application process is not straightforward. It is in this area where governments, from the local to the national level, can invest in simplifying online and offline processes using guidance from intelligent design principles.

In sum, more significant emission reduction efforts are needed if the 1.5- or 2-degree target is to be met. Carbon pricing is the key policy that can achieve this at the lowest cost. This is no secret and has been the consensus among environmental economists for the past thirty years. However, sufficiently high carbon taxes need broad acceptance by the public. In this paper, I have highlighted a few ways how increasing this public acceptance can be achieved. Smart climate policy should not stop there. Behavioural science and behavioural economics offer additional insights into how we can make carbon pricing more effective on the path to carbon neutrality.

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Critical materials, strategic elements and the green industrial revolution

Over the next 5-10 years many of the UK's large industrial sectors (including automotive, aerospace and energy generation) will see dramatic changes as we move from a society based on fossil fuels to one driven by electricity. Initiatives such as the government's Ten Point Plan for a Green Industrial Revolution are to be welcomed for their ambition, but without secure access to the technology-critical metals that are the building blocks of the green economy their vision will be impossible to realise.

Technology-critical metals such as rare earths, lithium and cobalt are essential for emerging clean-energy technologies including electric vehicle batteries, and permanent magnets used in efficient motors and generators. Demand for these materials is expected to grow exponentially over the next 20 years as a result of the global race towards next generation clean-energy technologies. These technology-critical metals have already been identified by the EU, US and Japan as being a serious supply risk.

The Birmingham Centre for Strategic Elements and Critical Materials (BCSECM) was set up in 2017 to help address this issue, after it became clear that the UK's exit from the European Union meant there was an urgent need to develop a national strategy. Working with academics and industry partners from around the UK, the team was able to bring together experts in mining, materials processing, manufacturing and recycling to consider how such a strategy could be developed. A policy commission, chaired by Sir John Beddington, was set up to provide a focus for this work and published its report Securing Technology-Critical Metals for Britain in April 2021. This article outlines the findings of this report.

Growing demand, precarious supply

The world's demand for raw materials is expected to double by 2060, according to a report by the Organisation for Economic Cooperation and Development. The requirement for metals is expected to grow even faster, with an expansion from 8 to 20 gigatonnes over the same period. In volume terms, much of this will be readily available, and easily recycled, metals like iron and aluminium – the UK currently exports much of this valuable raw material resource owing to a lack of onshore metals processing capacity. However, high-technology industries that make, for example, batteries and motors for EVs, the generators for wind turbines and the jet engines for aircraft are dependent on many technology-critical metals. It is predicted that by 2050 the EU will require 60 times more lithium, 15 times more cobalt, and ten times the amount of rare earths compared to the current supply to the whole EU economy. The new industrial strategy for the EU warned that Europe's transition to climate neutrality could replace today's reliance on fossil fuels with one on raw materials, many of which we source from abroad and for which global competition is becoming fierce.

The Covid-19 pandemic has highlighted the vulnerabilities of many supply chains and, as we scramble to shore up existing industries and expand into new job-creating sectors, the UK needs to ask itself serious questions about how it will access essential raw materials like technology-critical metals. To put this in perspective, such metals are vital to 7 of the top-10 UK export markets, with a value of more than £150 billion annually. The Faraday Institution predicted that the transition to manufacturing electric vehicles (EVs) could support 220,000 jobs by 2040. The ability to create and retain these jobs will depend on the UK's access to critical materials for batteries and rare earth magnets for EV motors and platinum group metals for the hydrogen economy.

Fig. 1 – sources of strategically important materials

Developing strategies

Technology-critical metals are often at risk of supply shortage for a number of reasons: rapidly expanding markets, geographical concentrations in certain parts of the globe (see Fig. 1), political factors (such as trade disputes, quotas and taxes), low recycling rates and a lack of substitute materials. None of these strategic elements are mined in significant quantities in the UK.

Accessing the raw materials is just one piece of the jigsaw. Without the processing technologies necessary to convert these technology-critical metals into, for example, chemicals, cathodes, alloys or magnets, we remain reliant on other countries for the critical components needed by our industrial sectors, and in many cases a large bulk of the value and jobs are in these parts of the supply chain. Highly skilled jobs, which would otherwise provide high-quality employment, are at risk if we do not capture more of the value chain in the UK. Some regions of the world, especially China, have invested heavily in the processing capability to convert these materials into products and, by doing so, now control the downstream supply chain.

Recycling or re-using the materials and components at end-of-life or from production scrap could provide a significant indigenous supply of technology-critical metals. However, there are technological, economic and regulatory barriers in some cases, which has meant that many of these materials are lost in the system. In fact less than 3% of rare-earth materials are recycled today worldwide. A UK-based secondary supply chain could be developed to re-use, recover and reprocess these materials and products, learning lessons from success stories with platinum-group metals and aerospace alloys, where world leading recycling technologies have been developed in the UK.

There are also opportunities for primary supply in the UK and by making strategic alliances overseas. The UK has major international interests in mining, through London registered companies, mine finance, equipment supply, consultancy services, and research and education.

Recommendations

The policy commission developed a number of recommendations informed by the challenges that end-users in crucial British industries have faced, as well as insight from across the supply chain for a number of key technology metals. Although the specific challenges around different materials vary, overall it is clear the UK urgently needs to develop policy responses to the critical materials challenge post Brexit.

1. The UK should create a single body responsible for developing strategic access to technology-critical metals. This body should link the primary and secondary markets for technology-critical metals and maintain an overarching strategy for the UK.

2. We should seek opportunities to diversify our access to primary resources of technology-critical metals, through resource diplomacy. This should form part of new trade negotiations.

3. Actively attract and provide support for large-scale strategic private investments for supply chain development of technology-critical metals both at home and abroad, and aim to make the UK an international refining centre for specific technology-critical metals by 2025.

4. Create individual task forces bridging primary and secondary materials for targeted technology-critical metals. These should identify the investments that would be required to set up primary processing, refining and recycling facilities for these materials.

5. Introduce incentives to encourage recycling refining and processing of technology-critical metals in the UK, particularly for processes that deliver a lower environmental footprint.

6. Consider measures to accelerate projects that seek to develop our indigenous sources of technology-critical metal (lithium, tungsten), including updating the regulatory environment.

7. Prioritise technology-critical metals in UK Research and Innovation strategies in areas such as the circular economy, developing substitute materials and efficient processing techniques for technology-critical metals.

8. Invest in the skills base in advanced materials processing and refining of technology-critical metals.

9. Urgently address the lack of data on material flows for technology-critical metals into and out of the UK economy.

10. Review waste management law with a view to promoting the recovery of technology-critical metals and ensure that there are no unnecessary regulatory barriers.

11. Encourage information exchange through the whole supply chain to ensure the challenges for recyclers are well understood by the product designers.

12. Consider how appropriate governance structures might ensure sustainability and resilience in the supply chain for technology-critical metals.

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Cities and built environment

06

The green belt, sustainability and England's housing crisis

The UK is currently facing profound governance challenges with the conjunction of the deepening housing crisis, climate change and the crisis of Covid-19 and the associated lockdowns. Rather than these problems being mutually exclusive, they are deeply interwoven with Covid-19 exposing and exacerbating housing inequalities. These include the vast differences in experiences of lockdown between those living in houses with plenty of indoor and outdoor space, often older, owner-occupiers in rural/semi-rural locations, and those living in apartments, often younger renters in city centres or inner cities. Moreover, people being largely confined to their locality has demonstrated the importance of the 20-minute neighbourhood, or having shops and facilities within walking distance of one's home, which could play a significant role in reducing transport and carbon emissions. Household energy generation is also a significant contributor to carbon emissions, 40% in the UK, so the built environment has a key role to play in addressing climate change. The central theme of this article is therefore that integrated, strategic planning is vitally needed to address these pressing, interlocking problems.

The situation pre-Covid

The causes of England's housing crisis are complex and contentious but it is widely agreed that it centres upon affordability and rising house prices which has increasingly priced (younger) people out of homeownership and into private rented accommodation which tends to be poorer quality stock, has less security of tenure and is more expensive. There are arguably a range of causes for high house prices, from international/national factors, such as interest rates and the financialisation of housing through to locational characteristics, such as the quality of transport links, schools and environmental offer. The crisis interrelates with the climate change agenda because, with land and housing already being so expensive, there are limits on how much buyers and housebuilders are willing to spend on a property's sustainability credentials, even after the experience of lockdown.

Likewise, the ageing nature and often poor quality of housing stock, austerity and the lack of incentives or requirements for private landlords, social landlords and homeowners to improve the energy efficiency of houses, such as insulation, double glazing or solar panels, limit the sustainability credentials of existing stock.

The Green Belt planning policy was introduced in the 1947 Planning Act and aims to prevent urban sprawl around England's largest cities and also some historic cities. This policy, alongside the broader planning system, is often blamed for exacerbating England's housing crisis by restricting housing development at the rural-urban fringe where demand for housing is the highest. In response, it is regularly argued that compact cities, dense brownfield development and protection of the countryside is vital to sustainability. Indeed, a fierce debate rages between those arguing that the Green Belt directs development further into the countryside with people then commuting back into cities (the 'leapfrogging' argument) whilst others argue that expanding existing urban areas through urban extensions is inherently unsustainable with the lack of public transport and facilities. Arguably the Green Belt does exacerbate the housing crisis although the evidence is complicated. Nonetheless, this dualism or polarised debate between solving the housing crisis and protecting the environment, or 'economy' versus 'environment' arguments, are unhelpful in productively moving the debate forwards. They miss the crucial role of planning, especially at a strategic, regional/sub-regional level, in addressing climate change. Indeed, many issues relating to planning, such as housing, transport, flooding and climate change, are inherently larger-than-local and strategic. It is also widely agreed that addressing affordability is key whilst ensuring sufficient services and facilities alongside development is vital to reduce car-dependency. Nonetheless, at the very point that planning is needed most, the system is weakend by many years of ideological attack, continuous tinkering and deregulation, under-resourcing and the lack of statutory strategic planning since 2010.

The impact of Covid and lockdown on housing

Covid and lockdown has arguably made the debate over the Green Belt more complicated and challenging. Most people in urban areas being unable to access the Green Belt for their recreational needs for many months and the importance of domestic/outside space in housing alongside access to local greenspace, has challenged the case for high density development in existing urban areas which is needed alongside the Green Belt. Indeed, Place Alliance found that the greatest predictor of satisfaction during lockdown was access to private greenspace so, unsurprisingly, owner-occupiers and those with older property were the most satisfied with their homes and private and social tenants alongside those living in high-rise buildings the least satisfied. Greenery was the most important aspect of one's neighbourhood with use of greenspace and local facilities peaking with a 5-minute walk and reducing sharply for longer than a 10-minute walk so Place Alliance actually recommended a 5-10-minute neighbourhood. There is now a strong case for perhaps more medium density development in existing urban areas and certainly for apartments with more domestic space and better access to outdoor space with there being rightly calls for minimum space standards in new developments, access to greenspace standards and a Healthy Homes Act. However, in order to still meet the housing needs of cities, lower density development in cities could exert more development pressure on the Green Belt, especially in cities which are tightly constrained by Green Belt, like Birmingham. Surveys suggest that households looking for more domestic, outdoor and local greenspace during lockdown have been moving to the countryside and rural-urban fringe also putting more pressure on the Green Belt. The lockdown has also shown the importance of local shops and services and the potential that the 20-minute neighbourhood has to reduce transport emissions. Nonetheless, vibrant and viable local centres to some extent depend upon density with Place Alliance recommending a minimum density of 50 dwellings per hectare (dpa) for all new development yet CPRE argue that the average density of developments in the Green Belt is currently 15 dwellings per hectare. The issues with 'leapfrogging' have also become less pressing with the increase in home-working andreduced pressure on transport systems in and out of conurbations. However, if people, especially families, increasingly move out of urban areas, the central challenge remains of the future and function of city centres and inner cities and the potential consequences for the many people who cannot afford to move out of these areas. To some extent, there is tension between what the market or volume housebuilders desire, in terms of wanting to build homes with gardens on the rural-urban fringe, and the outcomes which the planning system tries to deliver including development in cities on brownfield land supported by adequate services and facilities to reduce carbon emissions. Nevertheless, what is clear is the importance of local greenspace, with CPRE finding that 46% of adults visited more greenspace since the start of lockdown and 67% believing that protection and enhancement of greenspace should be a priority.

Policy responses: the government's response

The Government's policy response in the post-pandemic recovery has involved further liberalisation and flexibility in planning through extensions to Permitted Development Rights (PDRs), Class E and the Planning White Paper. PDRs allow a building to change in use without the need for planning permission if basic conditions are met. There have been well-documented issues with PDRs, especially converting office buildings into residential use, including the sometimes chronic lack of domestic space, windows and natural light in apartments, very poor or no greenspace provided alongside development and the absence of a requirement to contribute to improving local services or facilities - known as 'planning gain'. In September 2020, the Secretary of State for Housing, Robert Jenrick, introduced minimum space standards for PDRs for residential projects but PDRs have been extended since Covid with Class E allowing commercial, service and retail uses to be converted to residential. This has been widely criticised in the built environment profession as potentially radically altering local areas through losing valuable shops and facilities. Local authorities have lost yet more power to manage and improve their local areas whilst facing the headwinds of recession and profound economic and changes accelerated by Covid. The Planning White Paper proposes radically simplifying and digitalising the planning system through dividing up the country into three 'areas', growth, protect and renewal, with the Green Belt enjoying continued protection. Although housing figures would be given directly by central to local Government, the Paper is largely silent on strategic planning and lacked firm commitments on climate change.

Policy responses: recommendations

Given the pressing and fundamental challenges outlined in this article, arguably well-resourced, strategic and proactive planning is desperately needed. Solving the housing crisis should still be a very important policy aspiration but the system needs to move away from being overly focused on housing numbers to focus on the type and quality of housing being delivered alongside broader issues around climate and environmental change. This article therefore proposes recommendations surrounding the key spatial scales in planning – national, regional and local:

1. **National:**
A national plan is needed to spatially map out the Government's economic and transport investment priorities and how it intends to address climate and environmental change. This national plan would allocate broad areas of growth and restraint and review the overall purpose and spatial extent of the Green Belt through a national Green Belt conversation. The policy's purpose should move to being more environmentally-focused with an overall sustainability purpose aiming to ensure that the Green Belt plays a more positive role in addressing climate change through river restoration, for example. Alongside this, there should be a social objective which aims to increase recreation access to the Green Belt and stipulates that housing development should serve a 'social' purpose, that is, a certain proportion of housing should be affordable or offer tenures which are particularly needed, like social housing or housing for the elderly. This would help address the key issue of the affordability of new homes built in the Green Belt. National space and environmental standards for new homes could be introduced to ensure a level playing field across the country.

2. **Regional/sub-regional:**
A strategic plan could address the key environmental issues related to climate change, such as flooding, whilst also developing an economic strategy and allocating locations of restraint and housing growth. The strategic plan would explore the various spatial blueprints or growth options available, such as new towns, urban extensions or urban densification, over a broader spatial canvas than would be possiblelocally, so could make sustainability-based decisions.

3. **Local:**
There could be more scope for local authorities to manage non-strategic decisions, like the design and tenure of housing, alongside councils becoming more involved in delivering housing themselves. Local authorities could lead the way and benchmark in terms of environmental standards for new homes. In larger cities, perhaps more medium density development is needed to support local services whilst still permitting access to high quality greenspace. The amount of homes suitable for families built in cities should increase, that is, larger apartments with more discrete spaces. In Birmingham in 2018, for example, 81% of new dwellings were flats, 81% of new dwellings built in Birmingham in 2018 were flats, highlighting a lack of diversity in the tenures delivered. There should be more local partnership working and greater scope for local authorities to manage and shape their local centres to encourage more independent retailers and maybe the opportunity to introduce out-of-town parking levies etc. to help successfully deliver the 20-minute neighbourhood.

Conclusions

This article has set out some of the contentious and complex challenges involved in solving the housing crisis and addressing climate change, which have been exacerbated by Covid and lockdown. In many ways, climate change and the housing crisis are inherently 'wicked problems' – difficult to solve, long term and involving numerous policy areas and actors. However, the article has set out the power and potential of planning, especially strategic planning, to bring together various actors and interests in seeking to develop a vision for place. Strategic planning is vital in solving the housing crisis and climate change.

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Building better, safer, healthier cities for children and young people

It is estimated that by 2050, 'two-thirds of all humanity – 6.5 billion people – will be urban' and that before then, in the next decade, 60% of those in cities will be children and young people (Arup, 2017). A recent report in the Lancet argues that investment is needed to 'address the greatest threats to child health and wellbeing.' Children aged 0-17 bear the brunt of the negative environmental impacts associated with increased urbanisation, with '1 in 4 deaths of children under 5 attributed to unhealthy environments' (WHO, 2017). Air pollution, energy insecurity, food shortages and water vulnerabilities are critical threats which face young lives in cities and which are complicated by cross-cutting social factors like gender, income, disability and ethnicity. The environmental challenges facing urban children – now and in the future – are far more complex than we often think and are compounded by challenges associated with climate change. Creating better, safer, healthier cities for children and young people, now and in the future, should be a priority for governments, researchers, communities, NGOs, businesses and others.

Sharing evidence

Let us be clear on why addressing the environments of cities - and especially challenges associated with air, water and energy - matters for children and young people. According to the World Health Organization, '93% of all children live in environments with air pollution above WHO guidelines.' We know that children are more vulnerable to air pollutants than adults (WHO, 2018)and as a result this is one of the primary causes of death and damage to their health and wellbeing(UNICEF 2017). The first 1,000 days of human life is critical for development – for those children exposed to high levels of pollutants, this can have serious developmental and health implications (UNICEF 2017).

In terms of water, 'the quality and quantity of water that children rely on for survival is under threat… by 2040, 1 in 4 children will live in areas with extremely high-water stress' (UNICEF, 2020). International policy frames water as something to be 'accessed, used and controlled'(Hadfield-Hill and Zara 2019). However, research has shown that children's experiences of water go beyond simple questions of resource access. Children interact with water (and its absence) in a range of ways that may compound existing inequalities and that are structured by the values they learn from adults and their understandings of climatic events, such as drought or monsoon (Hadfield-Hill and Zara 2019).

Children's lives should also be at the centre of discussions about sustainable and equitable energy. Energy is critical to children's development and wellbeing (UNICEF, 2015) and equitable access to energy has a direct impact on poverty reduction. It has been proven, for instance, that more reliable street lighting can make urban spaces safer for girls, allowing them to access schools and therefore the education that can make a difference to their lives. Where that access is unreliable - for instance where it is controlled by criminal gangs in informal settlements - girls' education and their livelihoods may be at risk.

Critically, discussion about building 'child-friendly cities' has, so far, tended to focus on less overtly 'environmental' factors - looking instead at other important issues, such as children's access to education, or their ability to move around or play in urban places. However, it is time to pay greater attention to the environmental challenges that affect, and even underpin, children's experiences of cities - and especially the impacts of pollution, climate change and access to resources like water and energy. The case studies below bring some of these issues and complexities to life.

Case Study: Children living with the monsoon (Hadfield-Hill and Zara, 2019) (Hadfield-Hill and Zara, 2019)

Here the authors show how researchers and international agencies need to think beyond current water discourses, which are often framed around access, use and control. Of course, these are vital, but so too are a whole host of water challenges which impact young lives. This research from India showed how young people lived with water: how it shaped what they do, where they go and how it intersected with their play, belonging and ultimately lived experiences of inequality.
On the one hand, the monsoon brings with it relief from the heat and of course, for children, opportunities to play (see the photograph above), as one participant commented 'we sometimes drink good water of rivers. I and my friends swim… we wash our cows… we go to swim' (Male, 11). However, the research shows that the intensity of the monsoon rains soon 'infiltrates… their routines, homes, minds and bodies' perpetuating existing inequalities. Roads wash away, infrastructures are cut off, children cannot go to school. The homes people lived in impacted on their everyday experience of the monsoon - rain seeped into homes, mould grew up walls and young bodies were the most vulnerable - with fungal infections common among participants living in environments which buckle under the pressure of the rains. This research argues for a re-thinking of watery inequalities and urges us to 'think with the weather in uncovering the complexities of young people's entanglements with water.'

Case study: Living with and adapting to socio-environmental challenges in Sao Paulo's periphery (Börner et al., 2020; Börner et al., 2019; Science Magazine, 2021)

Research conducted with young people in the urban periphery of Sao Paulo has shown that the socio-environmental challenges facing young people are complex and often interconnected, impacting on various areas of their lives. On top of that, the impacts of climate change with more frequent and intense extreme weather events such as flooding, storms, and heatwaves exacerbate resource insecurity and produce so-called "wicked challenges", particularly affecting families in precarious housing conditions.

Research however has also shown that youth in the urban periphery of Sao Paulo possess important everyday knowledge about living with resource (in)security. Their stories reflect manifold realities which cannot be reduced to a single "one size fits all" portrait of their situation. Whereas some youth may point to issues around flooding, access to clean drinking water or to healthy food, others named concerns such as air pollution or lack of access to greenspace. At the same time, young people have developed ways of dialoguing with and adapting to resource scarcity through everyday adaptive actions, although these knowledge(s) and actions may not be immediately visible at a first glance, and therefore remain "hidden". They shared stories about practices of saving water, unplugging electronic devices before storms to avoid lightning strikes, creating support networks with family or neighbours, or engaging with local food production initiatives. And, despite all the challenges they are facing, youth also introduced another view of the periphery - a perspective which is one of hope, where nature is (re-) claiming its space in the midst of precarious urban settlements, with secret views, birds and butterflies, and where young people care about creating safer and healthy futures for themselves and their families.

Multiple realities in one: between resource scarcity, adaptive action, and the unexpected beauty of (peri)urban spaces (source: male, 12 years old)

Moving the public debate forward

It is essential that we address these challenges head-on in planning and designing, safer, more inclusive urban environments. As well as academics, governments, international agencies and civil society have an important role to play in addressing these critical challenges of our time. Indeed, this is the 'decade of action' for cities (World Cities Report, 2020). It is time to think differently about children and young people's relationship with cities, and to initiate a debate that focuses on the environmental and infrastructural conditions of cities as well as more detailed questions about the planning of urban public spaces. We have the evidence about the impacts of poor-quality urban environments on children and young people's lives - but action is needed.

Critically, children have a fundamental right to a safe and environmentally just city. We need to scale up from neighbourhood- or city-level debates - and academic research - to initiate a global debate about what makes a city not only child-friendly, but better, safer and healthier for children to live and grow up in. We also need to recognise that building better cities for children will make cities better for all urban residents - now and in the future. This debate needs to be genuinely inclusive and to take place in a variety of formats and media to answer some difficult questions, as follows.

- How can governments, policy-makers, academics, businesses, NGOs and communities work together to get a grasp of the complex, intersecting environmental challenges and threats facing children?
- What areas should we prioritise in addressing these complex challenges in creating child-friendly cities for children, now and in the future?
- How can priorities for creating a safe and environmentally just city for children be agreed and shared at a global level but also be sensitive to local conditions and concerns?
- How can cities (and the children who live in them) not only genuinely mitigate against but live well with the effects of threats to climate, air, energy, food and water?
- Placing children at the centre of these debates - listening not only to their experiences and worries but their aspirations and the solutions they propose - is imperative if we are serious about addressing these challenges. Engaging children and young people in debates about the potentials of urban space is also key to overcoming the stigmatization of urban peripheries and to creating dialogues of hope rather than shame. At the same time, while taking youth seriously, youth engagement also needs to be 'playful' to incentivize meaningful youth participation (Science Magazine, 2021; Bright Surf Science News, 2021).

Steps towards solutions

The next step is, then, to initiate an inclusive, global debate about how we can build better, safer, healthier cities for children. Below we suggest a range of starting points to for those debates, for gathering the knowledge we need, and, resulting from those debates for actually addressing the challenges which face children's lives in cities.
There is a need for more systematic co-production of research, consultation, policy-making with children (for instance through community-based mapping of relevant issues such as areas of environmental risk, access to food, provision of greenspaces). There is also a need, however, to create a platform to share that research within and between countries.

There could be further and more systematic consideration of the technologies to facilitate children's participation and meaningful interaction with policy-makers and other stakeholders (practitioners, researchers, youth-to-youth dialogue between activists and other young people). These could include bespoke mobile phone apps, social media, websites, and other media platforms as well as more 'traditional' forums for interaction such as workshops and conferences. These approaches could also include more experimental formats outside of 'formal' spaces, such as neighbourhood and city walks led by young people themselves to engage practitioners and decision-makers into their everyday realities first-hand.

The debate could be moved on by drawing on ways of thinking about and visualising the complex interactions of environmental and social challenges that urban children face (e.g. 'nexus approaches') as well as threats posed to resource security by environmental hazards. For instance, extreme weather events such as floods can have an impact on food security when food items become destroyed by the floods generally affecting families living in vulnerable conditions. Moreover, storms can negatively impact energy security as power cuts occur more frequently during or as a result of these events.

The debate and any proposed solutions need to seriously address the ways children adapt to and dialogue with resource insecurities and disaster risk. Yet, the overall approach should be one that helps children see not only the challenges and limitations but also the potentials of urban spaces and solutions to the environmental challenges they face. An approach that empowers children to perceive themselves as having ownership and being able to engage with their local environment is vital. This also means being hopeful that change is possible; hence, engaging with the potentials as well as the limitations of urban space is crucial.

We know much about how children experience urban spaces and what they want to see. There are also global conventions - such as the United Nations Convention on the Rights of the Child. Yet those knowledges and laws do not always translate into real, systematic action for child-friendly cities - whether in terms of planning or infrastructural solutions, or enshrining children's needs and voices into local or national laws.

We need to radically re-think city infrastructures to create better, safer, healthier environments for children and young people to grow up in. How can we reduce the number of childhood deaths attributed to unhealthy environments? How can we ensure that the air children are breathing in cities is cleaner and less damaging? How can we address the threats associated with air pollution, energy insecurity, food shortages and water vulnerabilities? It is not easy, our action and infrastructures need to be scaled up. Above all, we need interdisciplinary teams of engineers, city planners, architects, government officials and children's geographers (to name but a few stakeholders) to work together - we need to think and act big to address these critical challenges of our time. This also means addressing the impacts of climate change before it is too late, if we want to create safe and liveable futures for today's young generations.

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The carbon cost of our buried infrastructure – a case of out of site and out of mind?

A 2020 report by the UN Environment Programme (UNEP) estimated that the building sector accounts for a staggering 38% of world-wide energy-related CO_2 emissions and that the construction industry is responsible for nearly 30% of this figure. The report also highlights the increasing levels of emissions from the sector with 2019 reaching an all-time high of almost 10 GigaTonnes of equivalent CO_2. As such, the construction industry is, quite rightly, under pressure from the UK government to change practices and meet net zero carbon targets by 2050.

Organisations such as the UK Green Building Council are at the forefront of initiatives to reduce energy use and embedded carbon cost across the whole building sector. Understandably, the focus is on reducing emissions from the buildings themselves, be it during construction or over their whole lifecycle, and the embedded carbon cost of the construction materials is a very important part of this carbon footprint calculation. Whole-life embedded carbon assessment is nothing new and the Institution of Civil Engineers (ICE) originally produced embedded carbon data and calculation guides back in 2011. Most major public building projects are now required to calculate the "cradle to gate" and/or "cradle to grave" carbon impact as part of the design process. This is all good news, and the UK leads the world in the integrity and depth of its embedded carbon assessment processes. Nevertheless, are we doing enough to reduce carbon impact across the sector and are there missing elements to the analysis – a hidden cost, say, that is absent from the assessment? We believe there is something missing.

The embedded carbon cost in equivalent kilograms of CO_2 emissions per kilogram of material $kgCO_2e/kg$) is traditionally calculated for specific individual materials (cast concrete, say) but in reality, there are a multitude of choices (e.g., different concrete grades). It requires complex calculation routes to come up with an overall figure for a construction project and it becomes a numbers game (which suits engineers) to reduce the carbon footprint against project cost. It is also worth noting that profit margins in the construction sector are 2% at best and, therefore, reducing the embedded carbon cost on site is not a priority to most contractors.

Ultimately, there has to be some standard process for embedded carbon evaluation and good quality evidential information is vital for accurate calculations. The material-focused assessment is the best approach we have at the moment, but it does not account for the whole carbon cost of the development as, normally, the infrastructure systems feeding the buildings (water, gas, electricity, drainage, etc.) are not included in the life-cycle carbon assessment. Take water supply and drainage infrastructure as an example. There are estimated to be over 600,000 kilometres of buried water, sewage and drainage pipes in the UK that, ultimately, need replacing over a cycle of about 50 years. This is easily in the "cradle to grave" lifetime of a building but the carbon cost of this supporting infrastructure is not included in the overall carbon assessment – we argue it should be.

Modern-day pipes, sewers and water drainage systems are predominantly made of plastic, usually high-density polyethylene (HDPE) or polyvinylchloride (PVC), ceramic or cast and/or reinforced concrete. These materials have a high embedded carbon cost (see Figure 1a) but considerable effort is being made by manufacturers to reduce the carbon cost of their products. Through the use of 100% recycled plastics and reduced carbon concrete mixtures these 'low-carbon' alternatives have claimed embedded carbon reductions of between 50 to 80%. Good news, but the numbers do not tell the full story. By focusing on the primary construction material (the pipe in this case), the embedded cost of installation, including the excavation of soil and backfilling, is an afterthought in the carbon reduction process - essentially out of sight and out of mind. Under current pipeline installation standards, fresh aggregate materials (usually sand and/or gravel) are required for the fill materials around the pipe in order to guarantee installation integrity and quality – it is a pipe-soil system that is being provided. As such, there is a significant added carbon cost in the excavation and off-site removal of the original soils and the import of fresh aggregates to backfill the pipe trench and reinstate the surface.

These 'virgin' aggregates have an embedded carbon cost attributed to them (see figure 1a again) which is predominantly related to the transport cost of delivery to site. However, this is at least a 100 times less than the embedded carbon cost of the pipe materials themselves (concrete, plastic, etc.) and, consequently, the impact of using virgin fill materials is commonly overlooked in the overall carbon budget. The real carbon cost needs to take into account the true volume of the pipe trench (and therefore the volume of embedment and backfill materials) and the carbon cost of removing the excavated 'as dug' materials from site. A better way to look at the assessment is to take a "whole installation" view and define the embedded carbon per unit length of pipe installation (per 100m, say). This puts a different perspective on the overall carbon cost (see Figure 1b) and for a typical, 300mm diameter drainage pipe installation, would mean that the carbon cost associated with virgin aggregate use is almost equivalent to that of the precast concrete pipe itself. If the estimated 50-80% carbon reduction figures stated for low-carbon plastic and concrete pipes can be realised, then the highest carbon cost for any new pipe installation is likely to be associated with the backfill/embedment materials and trench reinstatement – a fact that might surprise some contractors in the pipeline sector.

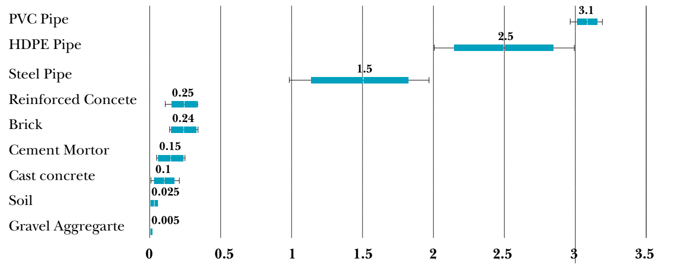
So, what can be done to meet our net carbon goals?

Obtaining alternative backfill/embedment materials from recycled sources is good start but using the excavated 'as dug' material from site is a better, more sustainable option. The materials will need careful sorting and perhaps processing on site, which will increase the monetary cost, but transport-related savings should balance this.

Research being undertaken under the University of Birmingham's ARLI programme (Alternative Raw materials with Low Impact) is already investigating how the sector can better use its waste streams (e.g., using recycled concrete as the embedment material). More interestingly, waste and by-product streams from the non-construction industries are also being evaluated including crushed glass, manmade fibres and even eggshells. Incorporating these alternative resources into the 'as-dug' materials on site helps condition and modify the physio-chemical properties of the excavated soils, ensuring a more even and stable backfill for the pipeline.

Regulations are also a barrier with current standards for pipeline installation not readily accommodating recycled embedment materials in their scope. Regulation change takes a long time but a working group of the Pipeline Industries Guild has been set up to tackle the issue head on. Consisting of members from academic groups, including the University of Birmingham, industry research centres (e.g., Water Research Centre) and highly experienced consultants, the aim is to transform pipeline installation practices which will then inform changes to current standards (e.g., BS 9295:2020 Guide to the structural design of buried pipes) with carbon reduction as the focus. The aim is to cut out 'off-site' material transport and eliminate the need for bought-in embedment materials (particularly virgin aggregates). Summed up in Figure 2, our initial research indicates that a saving of ~70% in embedded carbon could be made with practices transformed by 2030. Not quite net zero, but a long way down the road to the 2050 target.

a) Estimated Cradle-To-Gate Embedded Carbon Emission Values Of Common Pipeline Pipeline And Water Drainage System Materials



b) Estimated Cradle-To-Gate Total Embedded Carbon Emission Values per 100m for a Typical Drainwater Pipe Installation

Pipeline Installation Components	Estimated Equivalent Co_2 Cost In $Kgco_2$ E/Kg Per 100m Length
Soil Removal and Virgin Aggregate	610
Virgin Aggregate	320
HDPE Pipe Only	3,958
Cast Concrete Pipe Only	636
Reinforced Cast Concrete Pipe Only	1,590
Recycled HDPE Pipe Only	475
Low Carbon Cast Concrete Pipe Only	190
Low Carbon Reinforced Concrete Pipe Only	305

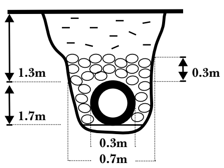


Figure 1. Estimated cradle-to-gate embedded carbon emission values for pipeline materials and typical pipeline installation components.

The pipeline manufacturers are playing their part as well. In a current InnovateUK funded research programme, Aquaspira Ltd are working with the University of Birmingham to develop almost 100% recycled composite steel and HDPE "SmartSense" pipes that can be installed with recycled or as-dug embedment materials and embedded sensing to autonomously monitor ground conditions. Key to this research is developing a better understanding of the detailed physical and geotechnical properties of the embedment material and how the whole pipeline installation performs when ground loading conditions change around the pipe.

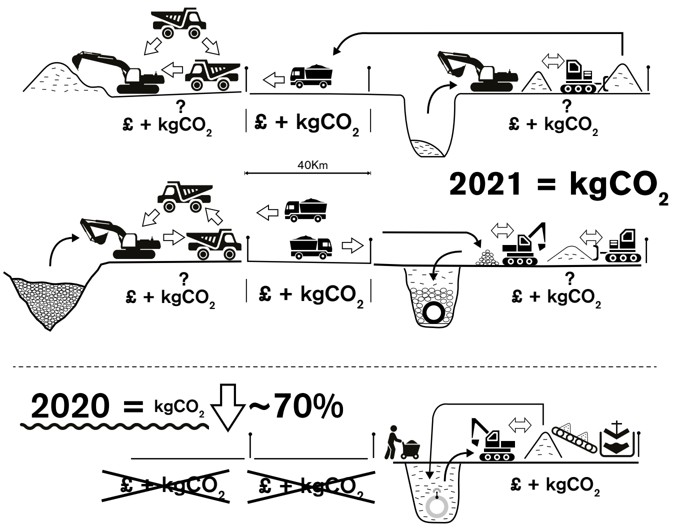


Figure 2. Reducing embedded carbon cost for pipeline installations – a move to using on-site materials and reduced transport.

Computational technology is helping in this regard with sophisticated numerical models being developed to create a digital simulant (or 'digital twin') of full-scale pipe installations. The research is utilising the testing capabilities of the new, £27millon UKCRIC National Buried Infrastructure Facility (NBIF) located on the University of Birmingham's Edgbaston campus. Full-scale trials will be conducted with the SmartSense pipes where ground and performance data will be used to develop and optimise the performance of the digital twin co-product. The UK is world-leading in the development of national digital twin capability and digital simulators will play an important part in establishing the baseline data needed to reduce our carbon impact. A recently released Royal Society policy briefing on "computing for net zero" recognises the contribution that Digital Twins can have towards meeting net zero goals; it states, "Digital twins make it possible to establish feedback loops to monitor, understand, optimise and reduce GHG emissions in many sectors". The work Aquaspira and the University are undertaking is just part of this digital infrastructure revolution with BIM (Building Information modelling) already being used to evaluate entire building life-cycle performance and carbon budgets from inception and design through to demolition and materials reuse. The evolution of BIM into whole-site and even city-scale digital twins will transform our long-term management of energy, water and waste and provide the underpinning technology to meet the data needs for a net zero sector. It is a very exciting time to be part of the buried infrastructure engineering community and the goal of net zero by 2050 is a challenging one, but very much achievable.

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Cities, the built environment, climate change and decarbonising urban lifestyles

Reducing the negative impacts of climate change requires revolutionary changes to urban lifestyles. Decarbonising the urban realm requires the alignment of alterations in transport, employment, spatial planning, and architecture to encourage and force alterations in social norms and related behavioural changes. Behaviour is embedded in deep seated expectations and practices.

The political, policy and academic debate has over-emphasized the development of technological solutions and efficiency savings to support the creation of low-carbon pathways (the supply side) and neglected a focus on why we require and use energy in the first place (the demand side). The latter highlights the importance of individual and collective actions and localised measures to support people with very diverse needs. Decarbonising the urban realm is a process requiring the alignment, and rebalancing of technological innovations with lifestyle alterations. This requires systemic and revolutionary change. This opinion piece identifies the extent of this challenge and, in so doing, provides a framework to guide policy development to accelerate global action towards the goals of the Paris Climate Agreement.

There is no one-size-fits-all solution to climate change: each place needs a unique blend of solutions. Climate change mitigation and adaption requires coordinated multi-scalar solutions – from households to streets and cities to nations. Everything must change including infrastructure provision, movement and flows of people, raw materials and products, and everyday living. This requires major alterations in approaches to planning and managing cities that will disrupt existing lifestyles. The built environment must be transformed to support short, medium and long-term changes. Different places and population cohorts must develop and apply different forms of mitigations and adaptations reflecting local circumstances. These include extraordinary global cities and more ordinary places including smaller towns and rural areas.

Decarbonising urban lifestyles can therefore only be achieved by focusing on process rather than output, a process that includes three interlinked activities:

1) Defining the extent of the challenge by applying a whole-systems approach to decarbonising urban lifestyles with a focus on systemic understanding.
2) Highlighting core risks related to behavioural adaptations including identifying barriers to change including existing norms and expectations.
3) Setting out a series of policy pathways to facilitate rapid decarbonisation of urban lifestyles.

Each will be explored in turn.

Defining the extent of the challenge and applying a whole-systems approach

In urban areas, climate change requires the creation and application of a whole-systems approach to the challenge of decarbonising urban lifestyles. This requires appreciation of the complexity and diversity of urban ecosystems and in identifying multi-scalar intervention points. Such an approach must be applied rapidly and systematically to all local contexts. Policy development must focus on the intersections between supply and demand informed by a detailed appreciation of different forms of urban living with attention given to intersectional challenges and blockages stressing socio-economic and spatial inequalities. This includes identifying energy-intensive lifestyles (and the ways in which these are produced, incentivised, normalised), infrastructure systems and production systems.

Consumption patterns differ between places and cohorts resulting in different degrees of carbon-intensive lifestyle. The most vulnerable cohorts tend to have less carbon-intensive lifestyles and it is these groups that will be most exposed to the negative impacts of climate change. A core challenge is identifying and understanding different urban lifestyles and the extent to which they reflect different forms of carbon intensity. This is about awareness, learning and developing understanding as well as being about responsibilities and communication. Culture is important in this context. Celebrity lifestyles, for example, are extremely carbon-intensive and play an important role in encouraging aspirational carbon-intensive lifestyles.

The application of a whole-systems approach to decarbonizing urban lifestyles must focus on:

1) Identifying and redesigning existing urban infrastructures (for example the utilities and mobility/connectivity related infrastructures) that underpin carbon-intensive urban living.
2) Identifying manufacturing systems that support and underpin carbon-intensive lifestyles including product design, packaging, and logistics with related approaches to recycling.
3) Develop a household informed understanding of the carbon-intensity of different approaches to urban living.
4) Promoting individual and collective ethical responsibilities and awareness to gather altruist momentum and a sense of ownership in tacking the climate crisis.

Barriers to adaptation and decarbonising urban lifestyles

All places are in a continual state of becoming, as individuals, groups and organisations adapt to processes of change and transformation occurring at different speeds and rhythms. The recent pandemic has highlighted the importance of temporary and more permanent adaptations for places and people. These processes of adaptation are place specific, even idiosyncratic, as decisions that have been made in the past influence and, in many cases, determine current investments. All cities are the outcome of path-dependent layers of decisions. This path dependency provides place-based distinctiveness as processes of ongoing incremental decision-making shape the physical, social and economic environments of place, but in turn creates barriers to change given the established intersections between supply and demand. Urban lifestyles are based upon conventions that have been created locally, nationally, and culturally. A convention is a constraint on action. These conventions, norms, or regularities are incorporated into routines that create specific forms of urban living. In urban areas, conventions include approaches to infrastructure provision, spatial planning, the design of residential units, consumption, approaches to mobility, and the everyday enactment of urban lifestyles.

Existing conventions and routines represent core barriers to adaptation and mitigation to climate change and to decarbonising urban lifestyles. Existing carbon-intensive urban lifestyles are the outcome of bundles of carbon-intensive routines that have formed to support specific cohorts' expectations and attitudes to urban living. They sit within wider systems, typically neo-liberal planning and the financialization of cities which tend to privilege speed and density to the detriment of people and places. A whole systems approach must be applied to identifying and understanding these bundles of routines that underpin carbon-intensive urban lifestyles and how they are grounded in wider approaches to the urban which in turn needs to be challenged.

Existing approaches to managing urban economies highlight the importance of 'growth' combined with 'productivity'. Both these are conventions that drive carbon-intensive lifestyles. Growth is driven by consumption and decisions made at the level of the household regarding expenditure. Every household expenditure decision creates and sustains employment, but also creates environmental pollution. These decisions must rapidly focus on developing carbon-light urban lifestyles. This requires informed consumer decision-making reflecting an appreciation of the relationship between consumer decisions and climate change as well as behavioural change. In the Netherlands, the Dutch government's ambition is to create gas free neighbourhoods, but homeowners have autonomy regarding the implementation of measures to decarbonise residential heating/cooling. This process requires carbon-intensive consumption options to be priced-out of the market through regulation and taxation. Currently, the expectation is that urban living will continue with limited adaptations. A good example is the replacement of the internal combustion engine (ICE) with carbon-light alternatives as the premise is that highly mobile urban lifestyles can continue.

A key barrier is found in incumbent technology. In the UK, the failure to develop a viable commercial alternative to the gas boiler will hold back decarbonisation. A gas boiler ban is being imposed from 2025 on installations in new residential units. Nevertheless, 85% of UK homes are heated by gas and a ban on all carbon-intensive heating appliances needs to be applied urgently. One challenge is the impact that this would have on incumbent manufacturers. Similarly, the shift towards e-commerce, the Internet-of-things (IoT) and Artificial Intelligence (AI) is reliant on carbon intensive server farms; zero carbon new technologies must only be adopted. This highlights the tensions between a range of priorities which are underpinned by political choices and agendas.

National and local policy must acknowledge that the continuation of existing urban lifestyles is impossible and that new approaches to urban living must develop. The challenge is that these alterations require radical and immediate change. COVID-19 has highlighted that rapid adaptation to a major societal crisis is possible. The danger is that the post-pandemic city will reflect attempts to return to pre-pandemic approaches to urban living. This is to be expected; existing conventions and routines will encourage households to return to pre-pandemic forms of consumption. A good example is the emphasis that is being placed on supporting and encouraging tourism including the return of air travel; only a small proportion of people fly, and an even smaller proportion are frequent flyers. The emphasis that is being placed on 'building back better' must include the decarbonisation of all urban lifestyles and radical alterations in demand. Here political commitment at all levels is key along with political leadership. This involves the introduction of radical deterrents; taxation must be targeted at the small proportion of high-income earners with carbon-intensive lifestyles.

Pathways to decarbonizing urban lifestyles – levelling up and levelling down

A critical barrier to decarbonisation of urban lifestyles is the absence of a highly visible and on-going debate on the need to make radical alterations to demand that would be reflected in urban lifestyle transformation. The existing approach assumes adaptation is possible based on incremental change; radical changes are required in which the outcome must be near to carbon-neutral urban lifestyles. Decarbonising urban lifestyles must be grounded in a concern for environmental justice. The danger is that policy will be influenced by the advantaged and will result in interventions that exacerbate existing forms of disadvantage, exclusion, and vulnerability within urban landscapes. The most advantaged will need to make the most radical lifestyle adjustments.

Developing new policy pathways to facilitate rapid decarbonisation of urban lifestyles requires the following actions to be taken by all governments:

1) Invest in research focusing on identifying key intervention points including understanding the drivers and facilitators of carbon-intensive urban lifestyles.
2) Apply a whole-systems approach to encourage and compel urban lifestyle adaptation. Carbon-intensive products, and related production processes, must be identified, replaced, or removed.
3) Major alterations to approaches to spatial or urban planning are required. Cities have been planned and developed to support and encourage carbon-intensive lifestyles. Spatial planning must be revised to facilitate the decarbonisation of urban living.
4) Prioritising flexibility over permanence and placing temporary urbanism at the forefront of new approaches to planning and managing cities focusing on the quality of decarbonised urban lifestyles.
5) A return to living locally must be at the basis of the development of new decarbonised lifestyles. This includes applying planning to encourage the formation of 20-minute neighbourhoods and promoting the circular city. Everyday living should be based on walking, cycling and carbon neutral forms of mobility with an emphasis placed on ensuring that most household everyday needs are available within a 20-minute return walk. This requires the application of holistic approaches to urban planning.
6) To reduce resource dependency, and the ecological footprint of cities, the flows of resources (input–throughput–output) of different urban functions (housing, industry, transport, etc.) should be analysed, and policies developed to force the reuse of resources, through principles of cascading (the subsequent use of resources for different functions based on the quality of the resource needed for the functions). This would require new approaches towards urban infrastructure governance.
7) The policy emphasis on levelling-up the most vulnerable must also focus on levelling-down carbon-intensive lifestyles.
8) Environmental justice must be central to the decarbonising urban lifestyles agenda. This includes acknowledging the importance of local solutions identified by local communities. All governments should encourage and facilitate processes of alternative-substitute place-making that represent a form of citizen-led place making but with a focus on decarbonising urban lifestyles.
9) Approaches that have been developed in the Global South should be identified and acknowledged as providing opportunities for informing new approaches to planning and living in cities. There is a tendency to assume that the best ideas come from the Global North.

The COP26 policy challenge and decarbonising lifestyles

The policy focus must focus on coupling supply and demand-side interventions. At the moment it is difficult for consumers to decarbonise their lifestyles – the structures, including societal norms and expectations, underpinning lifestyles incentivise high-carbon practices. These are hard to change, however we can start with more knowledge of the problem and our individual carbon footprints. *All products and services must come with a mandated grading of their relative carbon-intensity. This must be based on an agreed methodology for calculating total carbon-intensity.* Consumers would be able to make informed choices based on embedded carbon – this is not all of the story, but it is an important part of it. Governments would be able to introduce carbon-intensity sales taxes to encourage demand- and supply-side adaptations. The first government to introduce this approach will be the first to take Climate Change seriously.

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The amenity value of the climate

Enormous research effort has gone into determining the effect of Greenhouse Gas (GHG) emissions on the global climate, figuring out the impacts of climate change on the natural world and estimating the costs of abating GHGs. By contrast, much less effort has gone into valuing in monetary terms the impacts of climate change. In particular, there is in the climate change literature surprisingly little discussion about the direct impact of climate change on households. Although some of the impact of climate change on households might be felt through changes in incomes or changes in the prices of goods and services, the direct impact on households deserves far more attention.

Why might households prefer particular sorts of climate?

Why might households prefer particular sorts of climate (and hence care about climate change)? Put differently, why does climate have an amenity value? The reason is that households have basic needs for warmth, shelter, clothing, and nutrition. But whilst these needs can certainly be met by purchasing goods and services they are nonetheless influenced by the climate. Households inhabiting certain climates may find that they need to spend more than others. The most obvious example concerns households' need for warmth. Households can modify indoor temperature by heating or cooling neither of which is essential in milder climates. Households inhabiting such climates can use their income for other things. Likewise, climate alters people's calorific requirements and different types of climate necessitate different types of clothing.

The observation that basic needs are met in part by the climate has several consequences. First, it is likely that households inhabiting different climates exhibit different expenditure patterns even if they are confronted by the same prices and the same income. Second, it is likely that those households that are already poor might find themselves more vulnerable to a deleterious change in the climate (and more benefitted by a favourable change). Poorer households have a lot at stake from climate change.

The climate of the Mediterranean is often regarded as optimal probably because the cost of living is lower. How much would your household be willing to pay to inhabit the sort of climate that that the city of Nice currently enjoys is not a silly question; neither is the question of how much households in Nice are willing to accept as compensation for a change in their climate to one less pleasant. But despite it being difficult if not impossible to answer such a question directly nevertheless households are already implicitly valuing climates. Their implicit valuations reveal a lot about how households in different locations might be directly impacted by climate change.

A look at the different sorts of evidence

Empirical evidence exists that households indeed possess preferences over climate that can be measured in terms of monetary values. First, theory suggests that preferences for climate result in regional variations in house prices and wage rates. The price of properties in areas characterised by a more desirable climate is bid upwards whilst for wage rates the opposite happens. Remarkably empirical studies are able to provide estimates of the compensating price differential for marginal changes in climate variables i.e., the implicit value of an additional 1°C or 1mm of precipitation.

One problem with such studies is the assumption that individuals are willing to move considerable distances to eliminate the net benefits of different locations. This is problematic because climate variables differ only at considerable distances. A second problem is it may not be possible to use the same approach in small countries where the climate is homogeneous. It is for this reason that studies confine themselves examining the evidence for those countries that contain different climates e.g., the US or Italy.

Other evidence suggests that households inhabiting particular sorts of climates do indeed purchase different patterns of goods and services. This is of course consistent with the story concerning the influence of climate on households' needs. Analysing differences in consumption patterns is routinely undertaken to calculate household equivalence scales. These convey information about how much more money households with e.g., an extra adult or child require as a one-person reference household. Here however, the approach is used to calculate climatic equivalence scales i.e., how much extra money do households inhabiting a particular climate require to achieve the same utility level as another household living in some reference climate.

A third valuation technique asks households about the minimum income required for them to achieve a particular level of welfare eg, “subsistence only” or “good” or “very good” given the specific circumstances of the household. This approach also confirms that households inhabiting particular climates require very different amounts of income to achieve the same welfare level. The technique assumes that all households share the same understanding of different labels for describing various welfare levels. The most compelling way of finding the implicit value that households place on climate variables however is to ask households in different locations how happy or satisfied they are.

Studies connecting happiness or life satisfaction and climate

Many national statistical agencies conduct yearly surveys on happiness or life satisfaction / subjective wellbeing. These survey data are usually supplemented by information gathered on the precise socioeconomic conditions of the individual and information on their local environment. These data studies investigate the effects of the personal circumstances, macroeconomic conditions, and environmental quality on subjective wellbeing. Although most studies involve individual countries a few surveys are for multiple countries using the same questionnaire.

To better appreciate what such an approach entails, respondents to such surveys are typically confronted by a question such as the following one, which is taken from the World Values Survey: All things considered, how satisfied are you with your life as a whole these days? Using this card on which 1 means you are “completely dissatisfied” and 10 means you are “completely satisfied” where would you put your satisfaction with your life as a whole?

Using data from multi-country surveys, researchers have attempted to explain why people in some countries are less satisfied with their lives than those living elsewhere. Many variables have been touted as potential explanations, most often income as well as political and press freedom. Other important variables include macroeconomic variables such as inflation and unemployment, both of which are known to make individuals unhappy.

Over recent years researchers have also used these data to investigate the importance of climate to subjective wellbeing. This is achieved by comparing subjective wellbeing in countries characterised by different climates. There appears a remarkable relationship between climate and subjective wellbeing – survey respondents consistently report higher subjective wellbeing if they inhabit particular sorts of climates. Of course, some countries that have miserable climates such as Denmark (sorry Denmark) consistently report high levels of subjective wellbeing. But that is because Denmark also has a very high GDP per capita whereas the appropriate comparison is between countries where GDP per capita and everything else is held constant.

The sorts of climates that do most to promote happiness and life satisfaction appear to be climates *not* associated with extremes. Some papers find that countries reporting the highest subjective wellbeing are those remaining close to a mean temperature of 65°F all year round. Others find that higher temperatures in the warmest month reduce subjective wellbeing whilst higher temperatures in the coldest month increase subjective wellbeing. Such findings resemble the findings from the other approaches outlined above as what sort of climates households prefer. It is also possible to derive from these studies estimates of the implicit value of climate variables by asking what change in GDP per capita would be necessary to hold subjective wellbeing constant for a unit change in any climate variable. These amounts suggest that differences in climate go a long way to explaining cross-country variations in subjective wellbeing.

These such studies seek a relationship between measures of subjective wellbeing and climate not weather. Although there does appear to be a relationship between weather and measures of subjective wellbeing it is not appropriate to use such evidence to predict the impacts of climate change. The reason is that if what is currently unusual weather eventually becomes the norm households will adapt. What matters for climate change are differences in subjective wellbeing as evaluated by individuals that have already adapted.

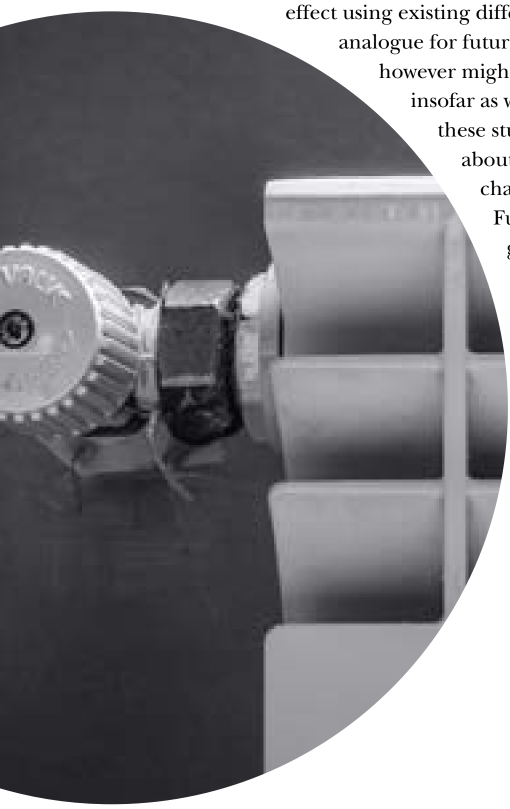
Problems that remain to be solved

The evidence suggesting that households have preferences for particular sorts of climate needs to be improved. For example, investigators have hitherto investigate the amenity value of only a limited number of climate variables, typically temperature. Other variables such as days of sunshine are less often included. Even temperature can be measured in different ways e.g., average temperature or maximum daytime temperature. Other studies use the concept of heating and cooling degree days employing 65°F as a base. This diversity matters because different ways of representing the climate frustrate attempts at comparing the results of different studies.

Another problem is that for many studies looking at subjective wellbeing and the climate the data is only available at the level of the country and not the respondent. This might be acceptable if all countries were as small as Malta. However, if one is including large countries such as the US then it becomes necessary to average the climates over the main population centres – hardly ideal. But that climate variables should still show up so strongly despite such problems simply serves to further confirm their importance.

It is also important to point out that not only do techniques identify the direct impact of climate on households they might also pick up some indirect impacts. More specifically, certain sorts of climate also support particular sorts of fauna and flora. Accordingly, it is impossible to determine the extent to which observed preferences for climate are in in fact preferences over different sorts of fauna and flora. This may not matter, but if the speed of climate change prevents fauna and flora adjusting things might start to look different.

Lastly, notice that the approaches outlined above are in effect using existing differences over space as an analogue for future climate change. This however might not be entirely adequate insofar as we are using the results of these studies to make predictions about the impact of climate change on future generations. Future technology and growth in incomes might mean that climate change is evaluated differently by future households.



Implications of the literature

Many studies referred to above report the amenity value of climate variables ie, the monetary amount that the average individual or household would be willing to pay to obtain / avoid eg, a 1°C rise in mean temperature or an additional 1mm of precipitation. These amounts might be positive or negative depending on the baseline climate and according to household income. Some researchers have actually combined these estimates with actual predictions about how climate is forecast to change in order to get an overall monetary valuation (although it is always necessary to be mindful of the fact that the direct impact of climate change on households is not the only way climate change might impact households). These calculations point to significant gains for households in some locations and significant losses in others. Climate change is certainly not a one-way street.

Valuing these the impacts of climate change in monetary terms may seem an arcane pursuit. However, demonstrating how much households in some countries stand to lose (and in some instances gain) might have a salutary effect on Governments in upcoming COP discussions for whom the question whether voters are willing to pay for costly measures intended to cut GHG emissions looms large. More generally, better estimates of the impacts of climate change expressed in monetary terms are likely to be of interest to anyone engaged in the sort of cost benefit analyses undertaken in the Stern Review.

Conclusions

It seems difficult to argue that climate change will not have a profound direct impact on households. Furthermore, households living in different locations will probably have a very different view of climate change. Households implicitly reveal their preferences for particular sorts of climate in a variety of ways. Greater use of this evidence, ideally expressed in terms of monetary values, will help to focus minds as the world decides how aggressively to limit GHG emissions.

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The air we breathe

Thursday 17 June 2021 was Clean Air Day and came as the Birmingham Clean Air Zone (CAZ) started to tackle road-transport related air pollution. Around 125 years ago, one environmental challenge was horse manure in the streets – with up to 100,000 horses in the largest cities, this was a highly visible issue. The West Midlands is known for the development of the motorcar, which alleviated this problem, but caused traffic jams and a less visible challenge – the fight for clean air.

The CAZ came into effect on 1 June, with charges for higher polluting vehicles entering the city centre. It is designed to target roadside pollution – nitrogen dioxide, primarily from vehicles with older diesels being major emitters. This is a local challenge: most of the NO_2 breathed in Birmingham is emitted within the city, so local actions reap local health benefits (eg, Covid lockdown falls in NO_2) – although care is needed to provide viable sustainable transport alternatives, and avoid displacing emissions outside the city and into other, potentially more vulnerable, backyards. As vehicle fleets modernise, emissions of NO_2 should fall, while increasing numbers of electric vehicles – ahead of the national ban on sale of most petrol and diesel vehicles in 2030 – will help mitigate the NO_2 challenge.

The other challenge is fine particles: PM2.5, which are small enough to penetrate deep into our lungs and bloodstream. Particulates come from sources such as combustion, agriculture and transport, and affect people across the region – requiring more coordinated approaches regionally and nationally. The UK's air quality legislation sets an objective for PM2.5 concentrations of 25 ug m-3 (annual mean, outside Scotland) while the WHO health-based guideline is 10 ug m-3. The latest science shows any reductions deliver health benefits. Exposure to PM2.5 and NO_2 leads to 28,000 – 36,000 premature deaths in the UK each year, while the CBI calculated that meeting the WHO guidelines for air quality could bring an annual £1.6bn economic benefit. These guidelines – set in 2005 – are due to be reviewed, and will likely strengthen in response to growing evidence of the health impacts of air pollution. The UK Government will shortly update PM targets within the new Environment Bill – a key opportunity to set the level of ambition for cleaner air over the coming decades.

Setting a target is one thing, but getting there is another. It will require changes in how we move around, heat our homes, power our cities and our industry. However, many of the changes needed have links (co-benefits) with actions to tackle climate change. Carbon emissions spread around the world and have global effects: CO_2 levels in Birmingham are similar to those in Beijing and Bermuda, requiring concerted international action. Conversely, most air pollutants are removed by atmospheric processes in hours or days – so local actions bring local health benefits: Birmingham can enjoy the benefits of cleaner air, irrespective of what happens elsewhere.

Many disadvantaged communities suffer the poorest air quality, and are most vulnerable to its impacts, so prioritisation of measures can help reduce regional health and social inequalities. A careful balance is needed between addressing the areas with the worst absolute air quality, and reducing exposure across the whole population. Provision of air quality data to those affected – making the invisible challenge visible – is vital.

Urban environmental quality impacts on human health and happiness but also economic growth. Cities that are delightful places to live and are perceived to have desirable residential amenities attract and retain talented individuals and this then is reflected in high new firm formation rates, economic growth and job creation. Clean Air Day plays an important role in reminding us that the air we breathe across the West Midlands impacts on liveability and livelihoods across the region. The WM-Air project at the University of Birmingham is measuring the sources of air pollutants, quantifying the air quality co-benefits from Net Zero actions, and working to evaluate air pollution health and economic effects across local communities – providing the science to enable policy choices which maximise the benefits from cleaner air.

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New approaches

07

The future is a foreign country: rethinking state behaviour on climate change as ill-treatment

"We are today perilously close to tipping points that, once passed, will send global temperatures spiralling catastrophically higher. If we continue on our current path, we will face the collapse of everything that gives us our security: food production, access to fresh water, habitable ambient temperature and ocean food chains. And if the natural world can no longer support the most basic of our needs, then much of the rest of civilisation will quickly break down.'

(David Attenborough, February 2021)

While climate change is already ravaging many parts of the world, with its most devastating impacts on the poor and vulnerable, the spectre of climate catastrophe haunts children and young people everywhere. As States' climate commitments and concrete actions are shown to be inadequate to avert the reaching of the irreversible tipping points that David Attenborough warns about, the prospect of a world in which more and more forests turn into deserts, cities drown, animals perish, and human devastation, violence and conflict escalate has led many children and young people to experience a phenomenon referred to as 'climate anxiety'.

Those experiencing climate anxiety endure constant feelings of fear, anguish and powerlessness regarding their own and their loved ones' well-being, as well as more generalised, prolonged anxiety and uncertainty about the current state and future of the planet. The phenomenon of climate anxiety contributes to both current and prospective suffering. As highlighted in a relevant scientific study, 'chronic stress from the acute and ongoing impacts of climate change may alter biological stress response systems and make growing children more at risk for developing mental health conditions later in life, such as anxiety, depression, and other clinically diagnosable disorders'.

The circumstances that children and young people facing the catastrophic consequences of climate change within their lifetimes find themselves in have led many to highlight the profound

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The Future is a Foreign Country: Rethinking State Behaviour on Climate Change as Ill-Treatment

intergenerational injustice inflicted on younger generations by those that currently hold the key to averting the worst of climate change. The inequities at issue are stark: children, young people and their offspring are condemned to bear the brunt of climate change in spite of being blameless and often lacking the political agency to effect change.

What I want to argue in the remainder of this piece is that what is currently being inflicted on children and young people through State (in)action on climate change can also be understood as amounting to ill-treatment, in contravention of one of the most fundamental norms of human rights law: the right not to be subjected to torture or to cruel, inhuman or degrading treatment or punishment. In particular, States are subjecting children and young people to inhuman and degrading treatment on account of the escalating suffering and real risk of catastrophic and irreparable harm to which State (in)actions are exposing them.

In a case currently pending before the European Court of Human Rights, six Portuguese children and young adults (aged 8 to 21) are arguing that 33 Member States of the Council of Europe (all 27 EU Member States as well as Norway, Russia, Switzerland, Turkey, Ukraine and the United Kingdom) are violating their rights under the European Convention on Human Rights (ECHR). *Agostinho and others v Portugal and others* will have already caused substantial disquiet for the respondent States, which have been invited by the Court to address whether the applicants are victims of violations of the right to life (Article 2 ECHR), the right not to be subjected to torture or ill-treatment (Article 3 ECHR), and/or the right to private and family life (Article 8 ECHR), taken individually or in combination with the right not to be discriminated against (Article 14 ECHR). The European Court of Human Rights raised the Article 3 question of its own motion, and I believe it was right to do so. While there is increasing acknowledgement of the impacts of environmental degradation and climate change on the right to life and the right to private and family life – as in the landmark 2019 Dutch Supreme Court judgment in Urgenda, for example – there is as yet little recognition of the way in which environmental harm dehumanises and degrades persons in a way fundamentally incompatible with the right not to be subjected to torture and ill-treatment.

Whether an act, omission or situation amounts to proscribed ill-treatment is assessed in a context-sensitive way to determine whether it reaches a certain 'minimum level of severity' (*Ireland v UK*, para 162). Treatment causing 'intense physical or mental suffering' (*Bouyid v Belgium*, para 87) is often found to be inhuman. Treatment that 'humiliates or debases an individual showing a lack of respect for, or diminishing, his or her human dignity or arouses feelings of fear, anguish or inferiority capable of breaking an individual's moral and physical resistance' (*Pretty v UK*, para 52) or 'inducing desperation' (*MSS v Belgium and Greece*, para 263) may be found to be degrading, even in the absence of serious physical or mental suffering (*Bouyid v Belgium*, para 87). More specifically, the European Court of Human Rights has associated inhuman and/or degrading treatment with 'feelings of fear, anxiety and powerlessness' (*Volodina v Russia*, para 75), 'feeling afraid, depressed and hopeless' (*Premininy v Russia*, para 81), 'intense fear and apprehension' (*Akkoç v Turkey*, para 116), 'constant mental anxiety' (*Rodić v Bosnia and Herzegovina*, para 73), and 'prolonged uncertainty' (*MSS v Belgium and Greece*, para 263). The Court pays close attention to any vulnerability experienced by the (alleged) victim. A distressing situation is more likely to cross the threshold of severity when endured by a person whose vulnerability is pronounced, as is the case with children (*Bouyid v Belgium*, paras 109-110). In determining severity, the European Court of Human Rights pays attention to the cumulative gravity of the particular circumstances experienced, and has recognised that if a person's circumstances disclose 'no prospect of an improvement in the situation', this compounds the gravity of the suffering endured (*Clasens v Belgium*, para 36).

The applicants' experience of climate change, like that of many children and young people around the world, corresponds in many respects to the dynamics of inhumanity and degradation described above: they are currently enduring prolonged and escalating fear, anguish and intense mental suffering emerging from climate change and its consequences – such as deadly forest fires occurring in their neighbourhoods – and facing the real prospect of catastrophic harm and further suffering befalling themselves and their loved ones. Given that they are effectively powerless to alleviate the phenomenon to which their fear attaches, they experience hopelessness and a sense of inferiority that is capable of breaking their spirit. It is not surprising, then, that a psychologist who specialises on climate anxiety in children and young people recently described climate anxiety to me as comparable to the death row phenomenon.

An even more powerful parallel may be drawn between the applicants' situation and that of individuals facing *refoulement*. It is firmly established as a matter of human rights law that forcibly removing someone to a place where there are substantial grounds for believing they face a real risk of torture or inhuman or degrading treatment violates their right not to be subjected to torture or ill-treatment. The obligation against *refoulement* under the right not to be subjected to torture or ill-treatment is absolute, and reflects the broader principle that authorities must

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refrain from forcibly placing someone in a situation where they face a real risk of grave suffering or distress (for example, placing a vulnerable person in solitary confinement). While bodies such as the European Court of Human Rights were initially hesitant to pronounce on prospective breaches of human rights, the rationale for doing so in cases of *refoulement* was the need to protect persons from irreparable harm. Although the circumstances may appear quite distinct on the surface, States contributing to climate change are similarly subjecting children and young people to a future that is guaranteed to involve real risks of irreparable harm which they are themselves powerless to avert. The prospective crossing of irreversible tipping points means that today's children and young people are facing real risks of loss of life and serious bodily harm as well as loss of their homes, livelihoods and access to basic resources through extreme weather events, natural disasters, infectious diseases and other 'sudden-onset' impacts of climate change and the psychological trauma and mental health deterioration emanating from such events, as well as escalating physical and psychological harm arising out of the 'slow-onset' impacts of climate change, including increased heat, drought, sea-level rise, water scarcity, food insecurity and air pollution, and ultimately the prospect of widespread violence, conflict and forced displacement in an increasingly inhospitable planet. The future is a foreign country, one might say: a dystopian place to which younger generations are currently being propelled through the collective (in)actions of those with the power to shape the course of climate change. States' (in)action is therefore subjecting children and young people to (a real risk of) inhumanity and degradation, in breach of the right not to be subjected to such ill-treatment.

What is being argued in *Agostinho* is that the respondent States are not complying with their positive obligations under the relevant rights – including Article 3 ECHR – read in light of their commitments under the 2015 Paris Agreement, which emerged out of COP21. The Paris Agreement can be taken to form the basis for delineating the measures States are duty-bound to undertake – including, as the applicants in Agostinho are arguing:

a) adopting 'deep and urgent' reductions of the emissions on their territory and on the other territories over which they have jurisdiction;
b) prohibiting the export of fossil fuels;
c) compensating for their emissions arising from the import of goods; and
d) limiting the contributions of multinational companies to global emissions through their activities abroad,

with a view to limiting temperature rise to 1.5°C in comparison with pre-industrial levels, it being understood that this would significantly reduce the risks and effects of climate change.

What is happening instead is that the escalating distress faced by the applicants in Agostinho and other children and young people around the world towards a situation that they are powerless to prevent, and which only the application of the most robust individual and collective regulatory State action can mitigate, is being met and compounded by official failings at best, and indifference or callous disregard at worst. An attitude of indifference or disregard by State authorities towards a powerless person's serious and/or potentially irreparable suffering that the State is aware of and in a position to alleviate violates the right not to be subjected to ill-treatment. Such an approach by State authorities is also fundamentally at odds with States' duty under the Convention on the Rights of the Child, in all actions concerning children, to accord primacy to and act in accordance with the best interests of the child.

The right not to be subjected to torture or ill-treatment is absolute as a matter of international human rights law, and that means that the obligations flowing from it are non-displaceable and non-negotiable. The application of this right in the context of climate change entails that States must take all reasonable steps within their power to stem the tide of climate change and avert the real risk of irreparable harm to which they are currently subjecting younger generations. The absolute right against torture and ill-treatment leaves no room for States to bypass these obligations.

The future that younger generations and their offspring face can seem alien and distant, the true scope of the climate catastrophe currently being unleashed upon them almost unfathomable or, perhaps, too uncomfortable for us to process. Yet it is being shaped by the governments of today, and it constitutes a human rights violation of epic proportions. Taking all necessary steps to reverse it is a non-negotiable obligation of all States at COP26.

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'No wealth but life': the role of the arts and humanities in tackling the climate crisis

When politicians and generals talk about winning 'hearts and minds', it is hard not to be cynical. The phrase seems to mask with good intentions a desire to dominate. But in the fight to stop climate change and the degradation of the natural world we need to win over the hearts and minds of the global population if we are to stand a chance of victory. As the survival of ourselves and countless of the other creatures with which we share our planet depends upon our success, this could not be more vital.

To be moved to act, whether as a leader or a citizen, you first need to be moved. People need to feel for themselves that they have a stake in the transition to a new and sustainable society; to know what they, personally, will love and lose if we do not make this happen; and to believe that with an act of collective will, we can. If we are to reach a sustainable future, we first need to be able to imagine it, not merely practically, economically, technologically but as human beings. Science is essential to this process, but it cannot achieve the transition we need on its own. It will need the help of both the arts and the humanities. Climate science and ecology tell us the risks we are facing but we need art and stories, television and film, music and poetry to help us feel for ourselves the impact of the loss of animals, plants and environments.

The arts offer hope and motivate us to act where graphs and diagrams remain remote and impersonal. Scientific data and discourses can be exclusive or obscure, while climate change, pollution and deforestation are all too often invisible. They are happening at a distance for many of us, incrementally, and even as individual disasters mount up and spread, it is hard to get over the cognitive dissonance caused by the wish for this not to be true, combined with the fair-to-moderate weather outside our own windows. The arts can make climate change vividly present and salient within our everyday lives. They can speak to a broad range of people of all ages and backgrounds in accessible and inclusive ways, and they engage us as communities, not just as individuals. After all, we can only solve the ecological crisis together. As the galvanising effect of music and theatre within the activist group Extinction Rebellion shows, the shared experience of art can help to sustain hope and motivate collective action.

If the arts can win over hearts, the humanities can help win over minds. Technological innovation will surely play a key part in slowing and potentially reversing climate change and in developing new and more sustainable infrastructures, but historical research and literary scholarship are vital too, to recover the voices of the people who saw before the rest of us the impact humanity was having on the natural world. We can still learn today from their observations and solutions.

In February 1872, in the second lecture from his series *The Eagle's Nest*, the Victorian prophet and social critic John Ruskin told an audience in Oxford that 'our ingenuity in the vindication, or the denial, of species, will be disregarded in the face of the fact that we destroyed, in civilized Europe, every rare bird and secluded flower'. It is almost one hundred and fifty years to the day since Ruskin alerted us to anthropogenic extinction. Not much more than a decade later, in 1884, he warned of anthropogenic climate change in his lecture *The Storm-Cloud of the Nineteenth Century*. In tackling these problems, we could do worse than start by adopting the remedy Ruskin himself proposed some years earlier in his trenchant critique of capitalism, *Unto this Last*, summed up in the phrase 'wise consumption'. If Ruskin's voice speaks to us from the early decades of rampant industrialisation and rapacious extraction, contemporary history comes together with oral tradition and indigenous knowledge in the voices of the Kogi people of the Sierra Nevada de Santa Marta in Columbia. Their BBC documentary *From the Heart of the World: The Elder Brothers' Warning*, now thirty years old, is a stark reminder of lessons we might have learned then and still need to learn now about how to live in harmony with the rest of the natural world and of the need to consider all human cultures and traditions in looking for solutions to the ecological crisis.

Science is our best guide to understanding the world as it is, but literature has the most to offer us in teaching us what it might be. In their different ways, poetry, myth, science fiction and fantasy all break open our narrow assumptions of what is possible, showing that we can indeed imagine new and different ways of living. For the Romantic poet Percy Shelley, poets were, as he gloriously put it in his 'Defence of Poetry', 'the hierophants of an unapprehended inspiration; the mirrors of the gigantic shadows which futurity casts upon the present'.

In her acceptance speech for a National Book Award Medal for Distinguished Contribution to American Letters in 2014, Ursula K. Le Guin echoed Shelley when she praised her fellow science-fiction and fantasy authors as 'Poets, visionaries, the realists of a larger reality'. Where 'so-called realists' risk entrenching the social order of the day, taking its intellectual limitations to be the actual limits of the world, the visionary imagination can throw off the shackles of prejudice and enable us to conceive of new worlds, including ones in which human beings sustain a less self-centred and self-destructive relationship with nature.

If this seems utopian, remember that we live our daily lives inside multiple and demonstrable unrealities – limitless economic growth, endless consumerism, anthropocentrism – fictions which are disguised as fixed natural laws or mere facts of life.

Close attention to literature gives us the critical distance we need from these contingent and transitory modes of being in the world. By reading and studying science fiction and fantasy, not to mention the diverse literatures of other cultures, times and places, we can help ourselves and each other to enter imaginatively into attractive and sustainable alternatives to the social, political and cultural systems we currently live in. Literature, then, no less that science, has a key role in bringing about the 'futurity' we need.

Finally, science needs the arts and humanities to show us the importance of values, not just costs. The policies and commitments made and thus far unmet at COP after COP have been predicated upon what is achievable within current models of economic growth, obsessive as they are over GDP. Ruskin's famous adage 'There is No Wealth but Life' should be blazoned on every wall of every meeting room at COP26 as a reminder that wealth as we have been pursuing it since around the time of his birth, two hundred years ago, has been at the expense of life, and that our very future – indeed the future flourishing of life itself, at least as we know it – depends upon us finding other ways to conceive of value. The reason we must act now cannot be reduced to economic ends nor the method to economic means, not only because of the moral imperative to respect and care for life at large and unborn generations but also because economics itself should serve the ends of life, not the other way round.

The arts, together with humanities disciplines such as history, literature and ethics are as integral to solving the ecological crisis as the sciences. To mobilise them we need to pursue not just dialogue but active collaboration between artists, humanities academics, scientists and civil society. At Birmingham, we have been developing two projects which point a way for these collaborations. Working with Mount Allison University in New Brunswick and several museums worldwide, we have launched the Symbiosis network to promote and enhance the role of the arts and humanities within natural history museums and collections. Symbiosis has enabled us to think globally. We have devised projects with colleagues in Europe and Canada and shared practice and expertise with museums from Paris and Portugal to Pittsburgh and Brazil through an online conference attended by delegates from over 20 countries across four continents.

Acting more locally, our closest and most far-reaching collaboration to date has been with the Oxford University Museum of Natural History. Founded in the 1850s, the museum was designed by the Irish architect Benjamin Woodward, working hand in glove with Ruskin and the Pre-Raphaelites and the scientists at Oxford University. They aimed to use the arts to celebrate nature and teach science. Since 2016, we have been working with the museum to revive that legacy under the banner Visions of Nature. Art exhibitions and commissions have drawn new audiences to the museum and helped them to apprehend the impact of environmental changes from the decline of British bees to the melting of the Arctic ice. Poets in residence have brought these changes home and helped visitors to fathom their own sense of loss and their hopes and to express them in poetry themselves. Following Ruskin's lead, the museum has embraced activism alongside public education, opening its doors in September 2019 to Extinction Rebellion for an 'Arts/Science Extravaganza' that saw 6000 people attend the museum in a single day.

More recently, literature scholars at Birmingham have begun working with Ruskin Land in the Wyre Forest as part of an interdisciplinary doctoral programme funded by the Leverhulme Trust at the Birmingham Institute of Forest Research. One project in particular aims to explore the imaginary forests found in fantasy literature to consider how they might enable us to think about woodlands in less anthropocentric and instrumental ways and how we can mobilise them to enrich public engagement with actual forests. Forests are home to most of the Earth's terrestrial biodiversity and are vital in our fight against climate change. Yet, all around the world – including in Britain – forests continue to face very real threats. Just 7% of all Britain's native woodlands are currently in good ecological condition, according to the Woodland Trust's *State of the UK's Woods and Trees Report (2021)*. The popularity of fantasy literature makes it a valuable resource for shaping public opinion. We will be running a series of experiments in Ruskin Land – itself John Ruskin's historical experiment to revitalise working people's connection to nature – using fantasy literature by William Morris, J. R. R. Tolkien and Le Guin. Through reading walks and discussions in the Dragon's Nest, fantasy readers and environmentalists will be brought together and stimulated to reflect on and reimagine our past, present and future relationship with forests.

These projects show how the arts and humanities can make a direct contribution to winning over hearts and broadening minds in the struggle to halt climate change and reverse the destruction of the natural world. In his 1872 lecture, Ruskin told his audience:

> *we shall be remembered in history as the most cruel, and therefore the most unwise, generation of men that ever yet troubled the earth: – the most cruel in proportion to their sensibility, – the most unwise in proportion to their science. No people, understanding pain, ever inflicted so much: no people, understanding facts, ever acted on them so little.'*

If these words don't resonate with our own moment and our own failings, then we have not heard them clearly enough. There is no doubt left about the facts and we must act on them in full. In the words of Ruskin's fellow Victorian, Alfred Tennyson, speaking as the Greek hero Ulysses,

> *'Tis not too late to seek a newer world'.*

If we seek it together, pooling the knowledge of science and the know-how of technology with the inspiration of the arts and the wisdom of the humanities, then we stand a decent chance of finding it.

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Six lessons etymology can teach us about tackling climate change

The IPCC Report of 2018 called for "rapid, far-reaching and unprecedented change in all aspects of society" in order to keep global warming to below 1.5°C (Gabbatiss 2018). For this to happen, I'd argue environmental reform must be as much a bottom-up approach as a top-down one; it must start with individuals asking what "aspects of society" they have the power to change. As an environmental poet, I approach climate change not just as a political and scientific crisis but as a communications crisis as well. A year ago, I began researching the history of words (etymology) to see what insight they might provide for us today. Here are six things I have learned so far:

1. We need to talk about it.

The word 'bear' comes from the Proto-Germanic **bero*, but that may not have been its original name. Some ancient tribes are believed to have ritually switched from using the word arktos to *bero (which means "brown") out of fear that saying the creature's real name might summon it. However, through the northern constellations Ursa Major and Ursa Minor ("the great bear" and "the little bear"), the word arktos ultimately survived in the words "arctic" and "antarctic" (Harper 2021). Recently I spoke to the poet Katie Hale, who had just returned from an exhibition in Antarctica. The scientists she travelled with, who were recording the effects of climate change in the region, urged her to address the rapid disappearance of sea ice in her work. They knew that the more we talk about the arktos, the more chance we have of summoning it back.

2. Language reminds us what we have lost and are losing.

The nature writer Robert Macfarlane wrote "as a species, we will not save what we do not love, and we rarely love what we cannot name" (Hamilton, 2021). The etymology of the word "penguin" provides an example of this. "Penguin" originally referred to a now-extinct species of bird, closely related to the puffin, that existed throughout the Northern Hemisphere as recently as 200 years ago. These penguins (also known as "great auks") looked so similar to the penguins of Antarctica that they were referred to interchangeably. Consequentially, when the original bearers of that name went extinct, they also all but disappeared from public memory (Pavid 2021).

In 2007, dozens of nature words ("otter", "acorn", "wren") were removed from The Oxford Junior Dictionary and replaced with words like "broadband" and "voicemail." Macfarlane collaborated with the poet Jackie Kay to produce a collection of acrostic poems, The Lost Words (2017), which aimed to rekindle interest in the replaced entries. Since its publication, The Lost Words has been adapted into theatre, film, music, card games, and puzzles. It has been used as an aid in classrooms and dementia hospices, and become the inspiration of a tree-planting campaign ('The Lost Woods'). Through grassroots fundraising efforts, there is now a copy of The Lost Words in every primary, secondary and special school in Scotland, as well as many counties throughout Wales and England. In short, this simple reminder of the names of natural things has become a rallying point for their celebration and protection (Hamilton 2021).

3. The wrong words can be violent. The right representation is vital.

The right whale gained its name because it was the 'right' kind of whale to be harpooned. Its name marked it as a target, and it was almost hunted to extinction before international whaling laws were brought into place (National Geographic 2021). Other whales such a the Minke whale and the Bryde whale were named after prominent whalers, which again reflects and perhaps contributed to the instrumentalist attitude humans have historically taken towards these species. I mention this because the words we use matter: 'Global warming' or 'climate breakdown', 'habitat' or 'timber', 'activist' or 'terrorist' - how we name things affects how we act towards them.

Global attitudes towards whaling shifted dramatically after the release of the album *Song of the Humpback Whale* in 1970, which arguably spawned the 'Save The Whales' movement. It enabled humans to stop seeing whales as distant natural resources but instead as beautiful, intelligent creatures capable of culture (Lewis 2020). Humpback whales are one of several species in this article associated with Antarctica. In including them, I am conscious that environmental communicators have often focused on the impact of climate change on such species instead of its impact on humans in the Global South. To me, however, the story of the humpback whale is an argument to buck that trend. Having good representation of the voices of those humans worst affected by climate change is vital for achieving climate justice.

4. The earth is our home.

In her speech at the 2019 World Economic Forum, Greta Thunberg used the metaphor "our house is on fire" to describe the ongoing climate crisis (Thunberg 2019). The metaphor reminded me that the root word for "eco" is the Greek *oikos*, which means "house" (Harper 2021). Eco is short for ecology; a field of study that highlights the importance of the natural world for our continued survival. Take for example plankton, which provide over half the oxygen in our atmosphere as well as serving as the foundation of our food chains and as a carbon sink. Our planet wouldn't be the place it is today without them, which is why it is so fitting that the word "plankton" is related to the word "planet" through the greek *planetes*, which means "wanderer" (Harper 2021).

Today, ocean acidification caused by increasing CO_2 levels threatens many species of plankton. It is this kind of ecological catastrophe Thunberg's metaphor is meant to make us panic about. However, too much panic can cause problems. Activists often experience "burnout" from imagining themselves in a burning house for too long (Khan 2021). Psychologists are now talking about "eco-anxiety", which comes from the words *oikos* and the Latin *angere*, "house choked" (Fawbert 2019). This brings me to my next point.

5. We need panic, but we need hope as well.

In the same speech, Thunberg also said "I don't want you to hope. I want you to panic." Panic is the core emotion of the climate movement in the same way pride is for the gay rights movement. The word "panic" comes from the name of the Greek nature god Pan, who whenever nature was under threat, would produce a sound so powerful it would scare the enemies of the natural world back into hiding (Atsma 2017, Harper 2021). In her speech, it might be argued that Thunberg tries to do the same thing.

Idealistic hope for a utopian future is certainly dangerous if it leads to political complacency. "Utopia" is a term coined by Thomas More in a book of the same name, in which he described his perfect world (More 1516). However, More's book was never meant to be a blueprint but a provocation. "Utopia", after all, is a pun; constructed from the Greek terms for both "good place" and "no place." I'd argue *prosperity* is created not from the expectation of future utopias but from the pursuit of hope ("prosperity" comes from the latin pro and spes which together mean "towards hope" (Harper 2021)). Panic inspires action, but is difficult to sustain; Pan, after all is the only god in Greek mythology who dies (Plutarch ~70CE). Just as a future sustainable world must be powered by both wind and solar, perhaps we need both panic and hope to power us to get to it.

6. Individuals can make a difference.

My research into the roots of language is "radical" in the term's original meaning of "rooted" (hence "radish" (Harper 2021)). Arguably, it is also in line with Deleuze and Guattari's concept of the "rhizome," a mass of roots that establishes "connections between semiotic chains, organizations of power, and circumstances relative to the arts, sciences, and social structures" (Deleuze and Guattari 1983). However, I would also see it as radical in the activist sense of making change at the grassroots, in trying to make a difference yourself.

Stephen Fry has noted that one interpretation of the etymology of "democracy" is "mob rule", an idea I'm interested in because of the links between "mob" and "mobilisation" (Fry 2015; Harper 2021). While the history of democracy is often tied to Athens, democracy also developed independently in Iceland in 930CE. The Icelandic Parliament is the oldest existing parliament in the world and formed grassroots-style at Thingvellir, a gap between two tectonic plates (Wallenfeldt 2021). "Thingvellir" means "valley of the Thing" because thing (the root of the modern homonym) is the Viking word for "parliament" (Harper 2021). Real democracy, I would argue, the kind born from inside the earth, contains within it a philosophy of individual agency we desperately need to embrace now.

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Matthew Cockram

Runner-up in the University of Birmingham Student Climate Change Writing Competition 2021

How can literature tackle climate change?

"Hard times are coming, when we'll be wanting the voices of writers who can see alternatives to how we live now, can see through our fear-stricken society and its obsessive technologies to other ways of being, and even imagine real grounds for hope. We'll need writers who can remember freedom – poets, visionaries – realists of a larger reality.'

~Ursula K. Le Guin, 2014

'Climate change' feels like an amorphous term but it encompasses the manifestations of anthropogenic destruction. This includes global emissions increasing thus heating up the atmosphere; land being lost to rising sea levels; biodiversity and habitats being destroyed and freakish, improbable weather occurring more in parts of the world - destroying livelihoods and lands which feed communities. We are struggling with ecological disasters due to widespread apathy and unsustainable practices. Companies responsible for over 71% of pollution are not motivated enough to change their environmentally damaging methods of production. There aren't policies demanding accountability and our consumer culture encourages rapid production rates. We have relied on science alone for too long to aid us in this dire climate crisis.

We need the mobilisation of people at all levels of society from big corporations and policymakers to individuals. The summation of our efforts is what can help tackle climate change. It is hard to visualise the attack on nature because some of us are living in a 'post-nature' world due to urbanisation and the legacy of industrialisation. Science alone has failed to generate a societal transformation. We need a way to imagine a culture focused on sustainability, conscious consumerism, and exploration of new ideas that can tackle this issue. How do we bring Climate change closer to us?

In Deep Iyer's social change ecosystem chart she recognises the importance of the storyteller as an effector of change. Writers are crucial in helping us imagine a voice for what is too easily reduced to just 'climate' or 'environment' or 'the planet'. Not only do we need people who can translate the gravity of our situation but we need writers to do what they do best- to give voice to the voiceless- as Richard Powers does in his story The Overstory; to translate the language of the earth, to create empathy for our world and help construct a culture where we are connected meaningfully to this thing we call 'nature'. Siobhan Adcock, author of The *Completionist*, recognises literature's ability 'to generate radical empathy, to enlarge our understanding of ourselves and our world, through people and stories that dramatise what a climate report or news story can't'. Literature works on our senses to make us feel - our brains are engaged as we read vivid imagery. As Helen Phillips, author of Some Possible Solutions, says 'fiction can make the threats of climate change visceral, not merely statistical. Fiction forces us to imagine it, to live it, at least for a time.' Literature will help imagine new solutions, make people care, and help us reimage our relationship with the natural world.

Fisola Kelly-Akinnuoye – Runner-up in the University of Birmingham Student Climate Change Writing Competition 2021

How can literature tackle climate change?

Literature can help scientists, policymakers and readers. What has been missing from the climate discourse is a humanistic approach to policy by helping leaders understand human cultures and our ecosystems. Those who dominate the climate change discourse aren't in close proximity to those who have struggled in the face of ecological disaster. Writers become vessels to tell the story of those who have suffered including nature. By reading their story brings the problem closer to those in conference rooms who are making policies. In N.K. Jesmin's science fiction trilogy The Broken Earth series the injustices that govern our world play a part in the fictional continent of the 'Stillness'. The novels show how institutions can perpetuate injustices, particularly towards marginalised communities. This is chillingly close to our world. The death of 8-year-old Ella Kissi-Debrah in 2013 due to acute respiratory failure, severe asthma, and air pollution shows how dire the climate crisis is. It is devastating that the loss of a young child is the moment of crisis when we should be working vehemently to prevent this from happening in the first place. We need to look at climate change from a humanitarian perspective- remembering that there are lives at stake, we need the tool of empathy as much as we need the quantitative and analytical tools of science. The government is advised by scientists, statisticians but what about writers who lend their voices to the world - who speak for the 'subaltern', who have imagined worlds beyond our own? The novel is an experiment, testing and trialing ideas much like that of a scientist. The writer's findings can be valuable contributions to decisions on environmental policy. Individual bodies must be aware that climate change is a method of extermination for the biosphere including its inhabitants - us. We are seeing the rise of climate migrants. The Climate and Migration Coalition has estimated that roughly 24 million people have been displaced due to weather-related issues in a single year. It shows us that we cannot compartmentalise climate change- it is an intricate network of injustice against people, the environment and animals.

Fiction can be used to affect policymakers but also readers. In an NPR article professor, Judith Curry describes it as 'an untapped way ... of smuggling some serious topics into the consciousness of readers.' The word 'smuggle' may carry connotations of illicit behaviour but it describes one of the virtues of the novel. It manages to show us not tell us important things. A didactic message often falls on death ears- no reader wants to be preached to so learning through a story is an organic way to impart information. Ecocritic Antonia Mehnert says climate fiction 'gives insight into the ethical and social ramifications of this unparalleled environmental crisis, reflects on current political conditions that impede action on climate change, explores how risk materializes and affects society, and finally plays an active part in shaping our conception of climate change.' Literature can help us picture potential futures and focus us on subjects we had never thought about. The Better Worlds project by The Verge is an example of literature and arts instilling hope and optimism in the face of the current crisis. In 'Monsters Come Howling in Their Season' by Cadwell Turnbull, the usage of AI is explored to help in climate disasters. 'Common' is a democratic AI database that does things like keeping an inventory of resources, provide 'regular clean-up efforts and forwards help requests' and 'notify first responders in time of emergency. Turnbull says he modeled this futuristic technology on popular voice assistant speakers like the Alexa or Google home device. Not only is the writer engaging with technological solutions but he also looks at ways societies can be remodeled in his interview. He is emphatic on a 'cooperative effort to save us' and how community ownership can protect towns and villages from disaster capitalism if they have aftermath plans and are in control of the rebuilding of their homes. Turnbull's story also considers the ethical issues of such technologies. The story is incredibly perceptive in its approach to climate disaster. It reminds us that we need to learn how to cultivate a relationship with the natural world. This job is for everyone - the public, the government, company stakeholders, etc. We must distribute and delegate according to scale. We must understand that this job is not 'to save the planet' it is to save ourselves.

All proposed solutions come with their limitations. We must interrogate who reads? Who reads climate fiction? Who needs to read it and how can we get them reading it? Journalist Dan Bloom speaks optimistically of cli-fi as 'a fiction genre that might help wake people up and serve as an alarm bell' - this can even mobilise people to care but we need infrastructure in place to spread these ideas organically. We need to get people thinking about how to reckon with the vastness of climate change. Broadening the readership demographic can get ideas into the hands of future humanitarians, scientists, policymakers, educators, etc

Literature as a solution may be critiqued as too optimistic or intangible for a situation that is so dire but we have tried science alone and it has not stopped us from continuing on the fast track to meeting and potentially exceeding the 1.5°C global warming increase target. Literature has a multiplier effect, ideas spread quickly and more fluidly than pdf reports, charts and figures. The fuel for change is hope and literature can provide this. It has taken years for the climate to get like this thus we can expect the reversal to be long and arduous, we need to sustain our efforts to reverse climate change. We must be quick to imagine new solutions when current ones fail. Writers who are producing this content need to be nurtured and need their stories to be read- and to have their story worlds materialise outside of the page. We must encourage the dissemination of climate fiction and ecocriticism in schools and higher education institutions- to cultivate thinkers and future problem solvers- we must make it our vocation to save ourselves by saving the environment. When people are informed they can demand legislation that is effective and targets those responsible. In her article, climate activist - Samia Dumbuya summarises the importance of a global effort 'to create collective impact and change, with something that is beyond our individualistic nature.' Stories are meant to be shared, they encourage everyone to immerse themself in the narrative, they make us think and feel. We need to be fully involved with our brains and our hearts- to tackle climate change.

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