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Towards a sustainable future: transformative change and post-COVID-19 priorities

A Perspective by EASAC's Environment Programme

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Science Advice for the Benefit of Europe

EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

Through EASAC, the academies work together to provide independent, expert, evidence-based advice about the scientific aspects of public policy to those who make or influence policy within the European institutions. Drawing on the memberships and networks of the academies, EASAC accesses the best of European science in carrying out its work. Its views are vigorously independent of commercial or political bias, and it is open and transparent in its processes. EASAC aims to deliver advice that is comprehensible, relevant and timely.

EASAC covers all scientific and technical disciplines, and its experts are drawn from all the countries of the European Union. It is funded by its member academies with some contributions from independent foundations and organisations such as UNESCO. The expert members of EASAC's working groups give their time free of charge. EASAC has no commercial or business sponsors.

EASAC's activities address many of the challenges highlighted by the United Nations Sustainable Development Goals, and include substantive, evidence-based studies of the scientific aspects of policy issues, as well as reviews and advice about specific policy documents. EASAC hosts workshops aimed at identifying current scientific thinking about major policy issues and at briefing policy-makers. EASAC also produces short, timely statements on topical subjects.

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Foreword

The word 'transformative' has entered current discourse from several directions, most recently in the European Green Deal which promises 'deeply transformative' policies. Before that, various analyses of the slow progress towards the United Nations Sustainable Development Goals concluded that 'transformative changes' would be required if humanity is to secure a sustainable future. The failure to reverse trends to worsening climate disruption and biodiversity loss is also said to require transformative change. But in steering national and regional societies, new words or concepts need to be translated into policy and action. Policy-makers and their public need to understand why 'transformative' or 'transformational' change is necessary if they are to support the conclusions of the advocates of change; otherwise these words risk becoming just another catch phrase.

'Transformation' implies a complete system shift across economic, financial and social domains to prioritise 'people, planet and prosperity' equally. While the COVID-19 pandemic has triggered a rethink or reset in some areas of our economy and stimulus measures may claim to aim at a more sustainable future, some measures at national level are still based on views of reviving an economy of the past with talk of 'shovel-ready' projects. Currently discussions are still very active on the aims and content of the large public expenditures planned, and the window of opportunity to 'get it right' may be short. Against this background, EASAC (the European Academies' Science Advisory Council) considered that an overview of the reasons for, and implications of, the calls for transformative change would assist policy-makers in designing policies for the future.

To be timely and to contribute to the current debate on priorities, EASAC did not create a new working group but called on the expertise within EASAC's Environment Programme to draw on previous EASAC science advice work and to write this Perspective. The Programme's analysis has been submitted to peer review by ten external experts nominated by EASAC member academies, and the final document was endorsed by all of these academies.

In this Perspective we first summarise trends that lead calls for 'transformative/transformational' change, with a focus on some of the systemic and structural failures that are driving our current unsustainable development. We then describe what is meant in practical terms for redesigning and redirecting our societies and, finally, the implications for the European Union's post-COVID-19 policies. Our aim is to assist policy-makers to better understand the underlying scientific aspects of the calls for transformative change, and thus to contribute to a more informed debate on the crucial major political choices that we are facing nationally, in Europe and globally.

Professor Christina Moberg
EASAC President

Summary

Purpose of this Perspective

As society moves further into the Anthropocene epoch, the concept of 'transformative change' has entered the policy discourse. Starting with the lack of progress towards the 17 United Nations Sustainable Development Goals (SDGs) and worsening trends in climate change and biodiversity loss, questions have been raised over whether current trends may present humanity with existential threats over coming decades. It is argued that incremental changes to 'business as usual' are failing and only a **transformative change** can safeguard humanity's future: namely a fundamental, system-wide reorganisation across technological, economic and social domains. The term 'transformative' has also featured in the European Green Deal (EGD) package.

This debate preceded the COVID-19 pandemic but is relevant to priorities in the economic stimulus measures which have already revealed tensions between returning to a previous 'normality' and engineering a transformative shift to align with humanity's future sustainability. Against this background, EASAC considered that an overview of the reasons for, and implications of, calls for transformative change could be helpful to policy-makers facing the challenges of deciding expenditure priorities.

The need for transformative change

Humanity requires a habitable planet on which to thrive and has to draw on nature's resources. Demand for energy and resources has been growing as a result of population growth and increased consumption to the point where scientific evidence suggests we are bumping up against some fundamental planetary limits. We summarise the evidence on these 'planetary boundaries', especially the core boundaries of climate and biodiversity.

In short, current **climate warming** is proceeding too fast to meet the Paris Agreement objective of avoiding dangerous climate change. Positive feedback effects that accelerate warming are already occurring. Moreover, the gap between what is needed in terms of reducing emissions of greenhouse gases (GHGs) and what is being achieved has been widening. Even the extreme effects of the COVID-19 pandemic have not reduced emissions to a pathway that is compliant with the Paris Agreement. This overview examines these trends and the evidence from palaeoclimate research of the risks of a shift to an inhospitable planet. At the same time, **biodiversity** is being lost at a rate that will weaken and degrade the services we rely on from nature, and undermine progress towards SDG targets in poverty, hunger, health, water, cities, climate, oceans and land. International reviews conclude that conserving and sustainably using biodiversity and achieving sustainability may only be achieved through transformative changes.

Why are global consumption levels unsustainable?

This Perspective examines the underlying drivers for increased demand arising from population growth and the growth in per capita consumption. On **population**, while fertility rates have declined in many countries, forecasts are for between 9.4 billion and 12.7 billion people in 2100. The SDG of empowering women and educating girls would, if fully met, help stabilise the population much earlier and result in a global population of less than today's by 2100. On **per capita consumption** the report shows the extent to which the impact of an individual's lifestyle can vary by several orders of magnitude, both between rich and poor countries and between the rich and poor in individual countries. Reducing environmental impact has to address both population and inequality drivers. A further driver is the increase in environmental impact arising from switching from plant-based protein to animal protein in the **diet**. Consumers' dietary choices have a major influence on climate change and biodiversity loss.

This Perspective also looks at factors influencing consumption choices, and how some economic practices are incompatible with sustainability. These include reliance on the imperfect measure of **gross domestic product (GDP)**, the way in which the value of the present is compared with values in the future (the **discount rate**), the difficulty of assigning an **economic value to environmental damage**, and the difficulty economic models have in assessing future risks from the **non-linear effects** of climate change and biodiversity loss. **Carbon pricing** is examined and found to be an effective but inadequately applied economic tool to mitigate climate change. Seeking economic growth assumes that technology will be able to decouple energy and resource consumption from GDP growth, but the potential for **decoupling** is limited within current socio-economic systems. The **financial sector** has also yet to adjust its priorities to drive the required shift from the fossil-fuel-based 'brown' economy to a renewable energy-driven circular 'green' economy.

The content of transformative change

Analyses from sustainable development and biodiversity scientists point to the need for transformations across all sectors: typically, human well-being and capabilities, and demography; consumption and production; decarbonisation and energy; food, biosphere and water; smart cities; and making full use of the digital revolution. Implementing change requires measures to (for instance)

- replace perverse subsidies with positive incentives for environmental responsibility;
- apply an integrated approach to decision-making across sectors and jurisdictions;
- take pre-emptive and precautionary actions to avoid, mitigate, and remedy the deterioration of nature;
- manage resilient social and ecological systems in the face of uncertainty and complexity;
- strengthen environmental laws and policies and the rule of law more generally.

Various tools and 'leverage points' are described in the Perspective addressing the drivers of unsustainable development. Change is likely to encounter strong resistance, and thus **social and political sciences** are important in planning. Barriers to change may derive from

- vested interests (e.g. those related to fossil fuels and unsustainable land and ocean practices; inertia and resistance to change in sources of investment finance);
- elite groups (e.g. wealth owners' resistance to the taxation needed to fund public services and investments);
- the limited capacity of governments to plan and implement policies with timescales of decades that straddle multiple electoral cycles;
- lack of public understanding and a resistance to change.

In achieving transformative change, the role and motivation of businesses is critical. This Perspective looks at work by the World Economic Forum (WEF) which concludes that US$44 trillion (over half of the global GDP) is potentially at risk from the decline of nature's services, and where transformative change could present business opportunities worth US$10 trillion per year and could create 395 million jobs by 2030.

Implications for the European Union and post-COVID-19 development

Transformations to a sustainable vision of a nature-positive, low-carbon resilient economy would involve shifts in the habits and social norms of billions of individuals across the world. As such, this has the characteristics of a 'wicked' problem. In particular:

- the strong evidence that current paths pose substantial and potentially existential risks to the future is manifested only incrementally and subject to uncertainty;
- beneficial effects of change are not easily quantified, and often apply in the future beyond the timescales of individual and government decision-making horizons;
- adverse trends are inextricably linked to current economic and political systems. Reform of a system that is no longer fit for purpose thus conflicts with some of society's core institutions, making consensus unreachable;
- attempts to adapt current systems may be hampered or hijacked by special interests that are powerful enough to stall or even reverse attempts to effectively address the basic problem.

This Perspective considers implications for implementing the EGD. The European Union (EU) can lead in the global response to sustainability challenges if businesses can work with national and Europe-wide policy and regulatory authorities, and the financial sector, to drive the necessary shifts in priorities and behaviour. In the age of the pandemic, scientists have also pointed to deforestation, uncontrolled expansion of agriculture, intensive farming, mining and infrastructure development, and exploitation of wild species as increasing opportunities for spill-over of diseases from wildlife to people. This therefore adds weight to the arguments for substantive change and a rejection of a return to the 'normality' advocated by stakeholders in the 'brown' economy.

There is already much commonality between the needs of transformative change and the priorities in the EGD. This Perspective supports the aims and objectives of the EGD and its recognition that sectoral change needs to be transformative. Achieving the goals of the EGD requires that the structural failures that have generated current drivers of unsustainable development should be addressed directly. Suggestions include the following.

- Replacement of GDP as a driver of policy with indicators of human well-being; indicators are urgently required that encourage advancing human development within the sustainability limits of nature.
- The paramount aim of decarbonising the energy supply must overcome the influence of special interests. Fossil fuels have already been awarded almost double the amounts allocated to renewable energies in the post-COVID-19 recovery funds in the Group of Twenty (G20) countries. Food and agricultural interests that are driving deforestation,

land clearing and over-fishing continue to be subsidised and escape paying for the environmental costs of their activities. Wealth inequalities and the huge disparities in consumption between individuals are also fundamental issues for society to address.

- Public awareness is a precondition for political action to tackle long-term issues such as climate change and biodiversity. Governments and professional bodies can provide information, but must also recognise the highly funded ‘fake news’, propaganda and misinformation from vested interests. There is a role for the scientific community which can develop better evidence-based tools and methods for multi-stakeholder engagement, as well as research and development. Also, for the EU’s Multi-Stakeholder Platform set up in 2016 to inform the implementation of the SDGs.

- A critical challenge is to convince industries and investors that transformative change is a better business opportunity than protecting the old ‘business-as-usual’ fossil-fuel-based economy. Options include rules on corporate governance encouraging businesses to pursue social and environmental sustainability as much as they pursue market share and shareholder value. Finance sectors and economic policy-makers should see the SDGs as the priority for exploring new opportunities, more effectively managing risks and securing a license to operate in the future. The groundwork laid by the European Commission (and the WEF) could lead to international sectoral platforms to develop consensus between the public, industry and policy-makers on transitions to a sustainable economy. Such collaborative decision-making processes are needed to reduce the adversarial nature of current systems.

In conclusion, this short overview presents the evidence that tackling climate change, loss of biodiversity and resource depletion requires addressing the underlying drivers of unsustainable consumption and production patterns. These conclusions challenge the social and political paradigm of at least the past 70 years where leaders have campaigned on the basis of continuing improvement in the traditional economy, with science and technology expected to allow economic growth to be indefinitely sustained. Recognising the realities of future human development within our finite planet will require a paradigm shift in the discourse of democracy’s political leaders to achieve a transformative cultural change in society.

This overview points to there being sufficient knowledge from the natural and social sciences to understand the planet’s environmental, economic and social crises. Science can help in several ways identified in this Perspective, but its impact will be limited if political systems fail to rise to the challenge of tackling these long-term threats. It is hoped that this short overview may assist policy-makers in understanding and assessing these long-term risks, and the importance of addressing the broader structural issues identified here.

1 Introduction

All countries adopted 17 goals for sustainable development in 2015. These 'Sustainable Development Goals' (SDGs) promised to build economic growth and end poverty while addressing social needs including education, health, equality and job opportunities, while at the same time protecting the environment, tackling climate change and preserving oceans and forests. Even before the COVID-19 pandemic, the review of progress in 2019 (Sachs *et al.*, 2019) found that '*No country is on track for achieving all 17 goals with major performance gaps even in the top countries on SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), SDG 14 (Life Below Water) and SDG 15 (Life on Land). Income and wealth inequalities, as well as gaps in health and education outcomes by population groups also remain important policy challenges in developing and developed countries alike*'. In particular, trends on climate (SDG 13) and biodiversity (SDGs 14 and 15) were concerning, land use and food production were failing to meet peoples' needs, and even in those areas where some progress had been recorded (human development indicators including poverty), the speed of progress was inadequate to reach the 2030 targets. In parallel with this lack of progress on the main goals, the omission of issues such as war, research and development, migration and cultural diversity have also come into question.

On specific targets, the Paris Agreement's call to limit global warming to 'well below' 2 °C above pre-industrial levels has yet to be matched by nations' pledges (Jiang *et al.*, 2019). While public concern about climate change is rising, many do not view climate change as a serious threat to themselves. The issue has also become highly polarised politically, with sustained and well-funded efforts to misinform the public and stall action (see, for example, Oreskes and Conway, 2010). Effective action is hampered not just by special interests but also the human tendency to discount future impacts (Weber, 2017). Equally, general support among the public and policy-makers against deforestation, biodiversity loss and species extinction has failed to reverse negative trends.

This has led some to conclude that adjusting 'business as usual' was failing to steer humanity towards a sustainable future, leading to calls for 'transformative' change: a fundamental, system-wide reorganisation across technological, economic and social domains, including paradigms, goals and values[1]. These conclusions straddle the United Nations (UN) sustainable development community (see, for example, Diaz *et al.*, 2019; TWI2050, 2018; Sachs *et al.*, 2019) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019). Within Europe, the European Environment Agency (EEA, 2020) notes that '*Europe will not achieve its sustainability vision of 'living well, within the limits of our planet' simply by promoting economic growth and seeking to manage harmful side-effects with environmental and social policy tools. Instead, sustainability needs to become the guiding principle for ambitious and coherent policies and actions across society. Enabling transformative change will require that all areas and levels of government work together and harness the ambition, creativity and power of citizens, businesses and communities. In 2020, Europe has a unique window of opportunity to lead the global response to sustainability challenges*'.

These pre-COVID-19 actions have now converged with the renewed focus on society's priorities triggered by the pandemic. The EU is among those with post-COVID-19 stimulus packages where synergy with the EGD is being sought. There appears to be broad support from Member States to make environmentally sustainable economic activity a focus of the post-pandemic recovery, and debate is underway on the required changes to the multi-annual financial framework and other financing tools. The European Commission proposed in May 2020 a 'Next Generation EU' recovery instrument, to '*help repair the immediate economic and social damage brought by the coronavirus pandemic, kickstart the recovery and prepare for a better future for the next generation*' and a Just Transition Fund which aims to alleviate the economic, environmental and social cost of areas most negatively affected by the transition towards climate neutrality (EC, 2020)[2].

Debate continues within the EU institutions (Commission, Council and Parliament) on budgets and priorities, and parallel debates and initial funding decisions in individual countries have already revealed tensions between calls for a return to the previous normality and those calling for a shift to a new set of values aligned with humanity's future sustainability.

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[1] As stated by Diaz *et al.* (2019), '*Reversal of recent declines—and a sustainable global future—are only possible with urgent transformative change that tackles the root causes: the interconnected economic, sociocultural, demographic, political, institutional, and technological indirect drivers behind the direct drivers … namely a fundamental, system-wide reorganization across technological, economic, and social factors, making sustainability the norm rather than the altruistic exception.*'

[2] For a recent analysis of the Just Transition Fund, see http://www.caneurope.org/docman/coal-phase-out/3639-2020-just-transition-or-just-talk/file.

Against this background, EASAC considered that an overview of the reasons for and implications of the calls for transformative change could be helpful to policy-makers. In this Perspective, we first summarise trends that lead calls for 'transformative/transformational' change, with a focus on some of the systemic and structural failures that drive unsustainable development. We then provide an overview of the concepts developed so far, and finally comment on the implications for the future design and priorities in the EU's post-COVID-19 priorities. This overview is intended to assist in identifying to what extent current plans and strategies within the EU in its post-COVID-19 and Green Deal initiatives may be impeded by the structural failures and inertia of our current socio-economic systems, and those areas that may require further attention if transformative change is to lead to a sustainable future.

As mentioned in the foreword, this Perspective has been prepared to explain the underlying science related to a current policy debate in a timely manner. There was insufficient time to appoint a dedicated expert working group, so the review was prepared within EASAC's Environment programme, peer reviewed by ten external experts, and the final document endorsed by EASAC member academies.

2 Why the need for transformative change?

In organisational management, 'transformative' change is the fundamental restructuring of an organisation's culture and work processes when they are no longer suited to current or future needs. In the context of the current debate, the 'organisation' is society, and the calls for transformative change are based on assessments that current development trajectories are incompatible with humanity's future sustainability or even survivability, owing to continued degradation of key natural systems that underpin human societies. So, what are the basic concerns here and the evidence on which they are based?

Sustainability is an issue with a global impact and reach, so a useful starting point is from research into human civilisations' dependency on our planet's natural systems (land, atmosphere, ocean, life, temperature, etc.). This has introduced the concept of planetary boundaries: that human civilisation can only survive and prosper within a certain range of planetary conditions, and there are thus limits on the variations that can be tolerated. It is by examining trends in these fundamental boundaries that existential threats to human societies can be identified. We summarise here some of the analyses and conclusions on these boundaries, trends in the two key boundaries of climate change and biodiversity, before discussing some of the underlying causes of our current situation.

2.1 Planetary boundaries

Human well-being depends on an Earth system that can provide the necessary environment for societies to evolve and flourish. Critical to these are climate stability and predictability, the ability to produce food, and the ability to provide security and stability for societies to develop. Rockström and others (Rockström *et al.*, 2009; Steffen *et al.*, 2015) identified nine processes underlying a stable and resilient Earth system, and proposed planetary boundaries within which humanity can continue to develop and thrive for generations to come. Crossing these boundaries increases the risk of generating large-scale abrupt or irreversible environmental changes with consequent effects on the civilisations they support. The boundaries are shown in Figure 1, together with estimates of their condition.

In Figure 1, it will be seen that biodiversity as part of biosphere integrity, and nitrogen flows from nitrate fertiliser, are critically exceeded, while phosphorus flows, climate change and land-system change are exceeded. Of the other boundaries, two have not yet been quantified while the others are judged to still be within their boundaries. Of the latter, stratospheric ozone has been protected by international action under the Montreal Protocol, but another (ocean acidification) is continuing to worsen in line with the increases in atmospheric carbon dioxide (CO_2). We focus here on the two core boundaries of climate change and biodiversity; the state of the other boundaries as expressed by the Stockholm Resilience Centre is summarised in Box 1.

2.2 Climate change

Despite the sciences, including the social sciences, now understanding climate change and the associated

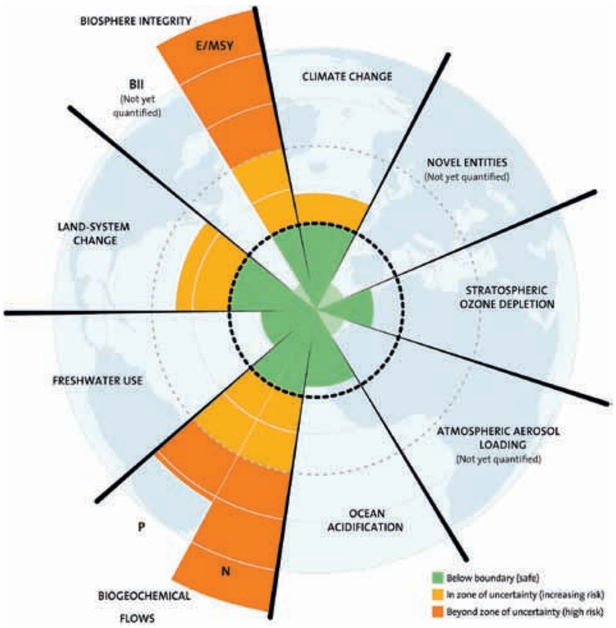


Figure 1 Planetary boundaries and their status (Source: Stockholm Resilience Centre: J. Lokrantz/Azote based on Steffen et al., 2015).

Box 1 Status of the planetary boundaries

Stratospheric ozone depletion
The stratospheric ozone layer in the atmosphere filters out ultraviolet radiation from the sun, and weakening threatens a higher incidence of skin cancer as well as damage to terrestrial and marine biological systems. The appearance of the Antarctic Ozone Hole in the 1980s triggered international action to prohibit ozone-depleting chemicals, and the Hole has stabilised and recently decreased damage as a result of the measures agreed through the Montreal Protocol.

Chemical pollution and the release of novel entities
Emissions of some toxic and long-lived substances such as synthetic organic pollutants, heavy metal compounds and radioactive materials have been addressed through a range of international agreements (e.g. the Stockholm Convention on Persistent Organic Pollutants, bans on mercury, cadmium, etc). Novel entities may include genetically modified organisms, nanomaterials, micro- or nano-plastics and have not yet been quantified.

Climate Change (see section 2.2)

Loss of biosphere integrity (biodiversity loss and extinctions) (see section 2.3)

Ocean acidification
Around a quarter of the CO_2 that humanity emits into the atmosphere is ultimately dissolved in the oceans, altering ocean chemistry and increasing acidity. This increased acidity reduces the ability of many marine species to capture the carbonate ions necessary to form shells and skeletons. Compared with pre-industrial times, surface ocean acidity has already increased by 30% and will affect ocean ecosystems in unpredictable ways. Controlling this is closely interconnected with climate change mitigation through reducing CO_2 emissions.

Freshwater consumption and the global hydrological cycle
Water is becoming increasingly scarce: by 2050 about half a billion people are likely to be subject to water stress. Human modification of water bodies includes both global-scale river flow changes and shifts in vapour flows arising from land-use change. These shifts in the hydrological system can be abrupt and irreversible.

Land-system change
Land-use change (especially as a result of agriculture and urban/infrastructure expansion) has affected already 75% of the Earth's terrestrial area. It is one driving force behind the serious reductions in biodiversity, and affects water flows and biogeochemical cycling of carbon, nitrogen and phosphorus and other important elements. Even though most land-cover change occurs on a local scale, the aggregated impacts can have consequences for Earth system processes on a global scale.

Nitrogen and phosphorus flows to the biosphere and oceans
Human activities convert more atmospheric nitrogen into reactive forms (via fertiliser production and use) than all of the Earth's natural terrestrial processes combined, and pollute waterways and coastal zones. These can become oxygen-starved as bacteria consume the blooms of algae that grow in response to the high nutrient supply. A significant fraction of the applied nitrogen and phosphorus makes its way to the sea, creating 'dead zones' which reduce ocean productivity and fish catches.

Atmospheric aerosol loading
Aerosols play a role in the hydrological cycle affecting cloud formation and global-scale and regional patterns of atmospheric circulation, such as the monsoon systems in tropical regions. They also have a direct effect on climate by changing how much solar radiation is reflected or absorbed in the atmosphere. However, the behaviour of aerosols in the atmosphere is extremely complex, and planetary boundaries have yet to be established.

The European contribution
The EEA's State of the European Environment (EEA, 2020) assesses planetary boundaries in the European context and concludes that Europe overshoots its share of the global 'safe operating space' for several planetary boundaries. Moreover, when the environmental impact of all Europe's consumption (including imports) is considered, trends are not improving.

Source: adapted from https://www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries/about-the-research/the-nine-planetary-boundaries.html.

environmental, economic and social impacts better than ever, political debate remains polarised. It may thus be helpful to mention the long history of climate research and the lack of uncertainty over the basic processes involved. Indeed, scientific understanding of the origins of the greenhouse effect dates back almost 200 years to the early 19th century. The first estimate of climate sensitivity (the average warming for a doubling of CO_2 atmospheric concentrations) by Arrhenius in 1896 (3 °C) remains very close to the midrange of today's calculations. Little has thus changed in the basic physics of global warming in over 120 years, and even oil companies have been shown to have reached similar conclusions (subsequently suppressed) as far back as 1977 in their own research (Oreskes and Conway, 2010; Scientific American, 2015).

International agreement to combat climate change was established in 1992 through the United Nations Framework Convention on Climate Change (UNFCCC).

The Intergovernmental Panel on Climate Change (IPCC) is the scientific advisory body of the UNFCCC and was established in 1988, since when it has conducted detailed scientific assessments of the state of the climate approximately every 5 years. The next (sixth) assessment is due in 2021.

Although several greenhouse gases originating from human activity contribute to global warming, the dominant one is CO_2 (approximately 76%). Concentrations of CO_2 are measured in many locations but a continuous set of data from Mauna Loa in Hawaii is most often shown, and can be placed into the historical context using ice core data, as shown in Figure 2. This shows that atmospheric concentrations continue to rise at approximately 2 parts per million (p.p.m.) per year and are currently near 418 p.p.m. When Mauna Loa measurements started in 1957, concentrations were approximately 315 p.p.m., the concentrations at the launch of the IPCC were about 355 p.p.m., while those at the time of the Industrial Revolution were approximately 280 p.p.m. The associated increase in average global temperatures is shown in Figure 3.

Carbon dioxide has a long lifetime in the atmosphere and so emissions today contribute to warming centuries into the future. The IPCC has established carbon budgets that place limits on future emissions if warming is to be limited to a given temperature. The Paris Agreement undertook to limit warming to less than 2 °C and to have aspirations of limiting to 1.5 °C (relative to pre-industrial temperatures). Since the average global surface temperature is already exceeding 1 °C, this leaves little room for continued emissions at current rates if the lower target is to be achieved[3]. Remaining budgets for the 2 °C limit are still debated but assumed to be in the several hundred gigatonnes (equivalent to just one to two decades of emissions at current rates). As a result, emission pathways that comply with Paris Agreement targets require very steep reductions. In contrast, before the COVID-19 outbreak reduced industrial activity and transport, emissions were still rising each year. The contrast between emissions and the requirements for compliance with Paris Agreement targets are shown in Figure 4, where even the extreme effects of the pandemic have not reduced emissions to the degree needed to return to a pathway compliant with the Paris Agreement.

The failure (before the COVID-19 pandemic) to stabilise emissions, let alone sharply reduce them, shows policies up to now based on incremental shifts in historical business-as-usual have been inadequate. In addition, events since the Paris Agreement have

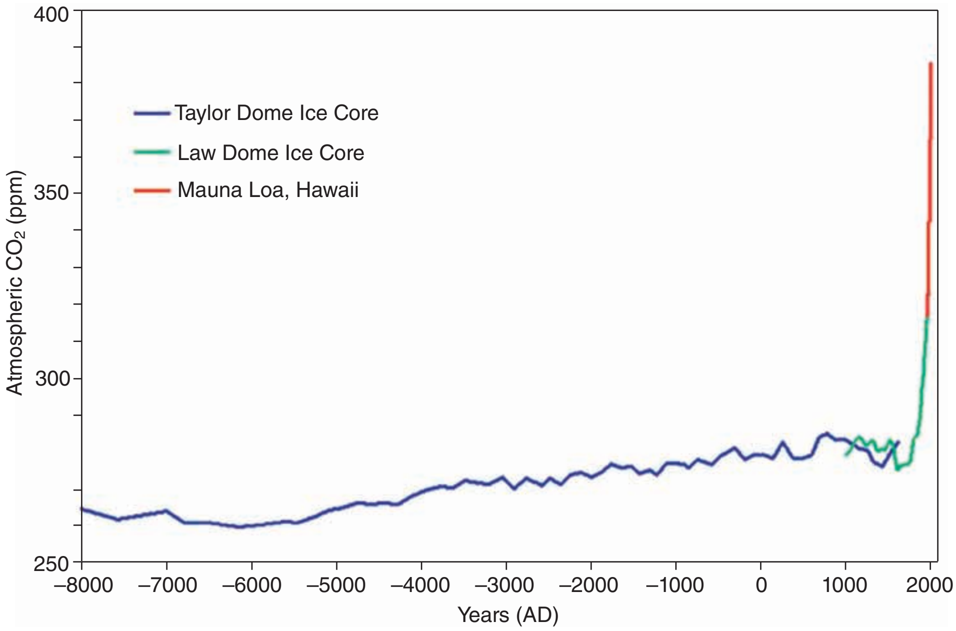


Figure 2 CO_2 levels (in parts per million) over the past 10,000 years. Blue and green lines from ice core measurements (NOAA at https://www.ncdc.noaa.gov/data-access/paleoclimatology-data and CDIAC at https://cdiac.ess-dive.lbl.gov/trends/co2/lawdome.html. Red line from direct measurements at Mauna Loa, Hawaii (https://www.esrl.noaa.gov/gmd/ccgg/trends/). Figure courtesy of https://www.skepticalscience.com/co2-measurements-uncertainty.htm.

[3] Nine model calculations in 2018 ranged from already having exceeded the budget for 1.5 °C to just over 10 years at current emission rates (see https://www.carbonbrief.org/analysis-how-much-carbon-budget-is-left-to-limit-global-warming-to-1-5c).

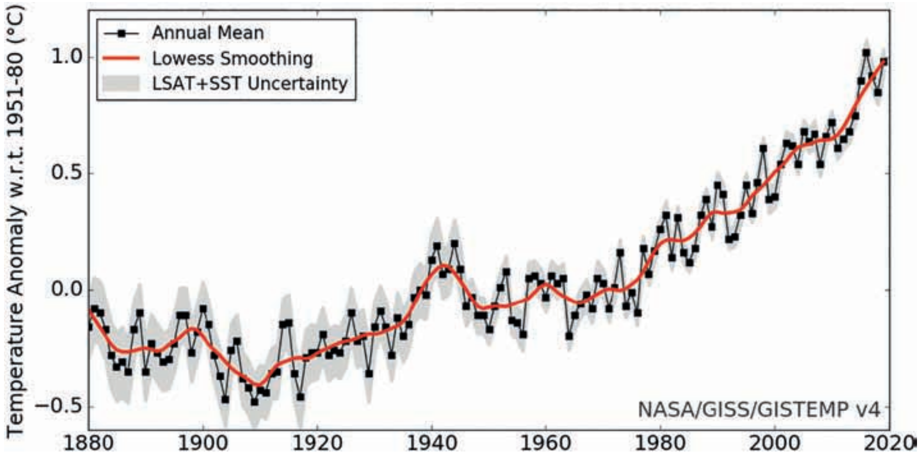


Figure 3 Global mean surface temperature change since 1880. Sources: NASA GISS, GISTEMP Team, 2020: GISS Surface Temperature Analysis (GISTEMP), version 4. NASA Goddard Institute for Space Studies. Dataset accessed 6 October 2020 at https://data.giss.nasa.gov/gistemp/; Lenssen et al. (2019).

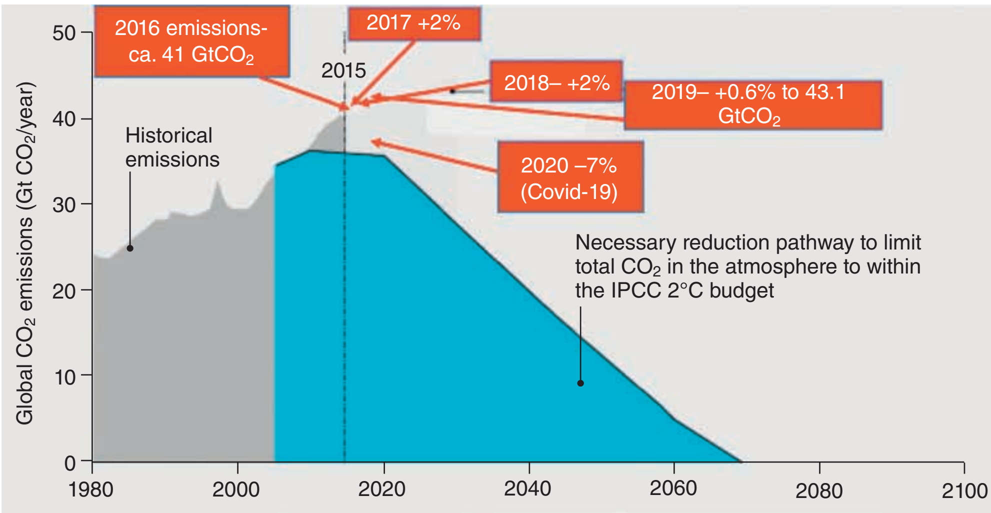


Figure 4 Emissions reduction pathways required to meet Paris Agreement pathways and recent global emissions (adapted from Anderson and Peters, 2016). The blue area shows the emissions pathway that would be required (starting in 2011 on the basis of the IPCC fifth assessment) if the Paris target of limiting warming to 2 °C were to be met. Annual emissions since have increased the gap between actual emissions and what is required. Even the rapid reductions due to the COVID-19 pandemic have not returned emissions to their 2011 level (CO_2 emissions from www.GlobalCarbonProject.org).

further undermined the chance of avoiding dangerous climate change. For instance, these have included the following.

- Political developments such as measures that reverse former climate mitigation commitments in government policies in major economies such as the USA and Brazil.
- Climate sensitivity. This had changed little from Arrhenius' estimate of 3 °C 120 years ago (the last IPCC report placed it between 1.5 and 4.5 °C). However, a very recent analysis (Sherwood *et al.*, 2020) narrowed down the range of climate sensitivity to between 2.6 and 3.9 °C (median of 3.25 °C), while other recent estimates reviewed by Palmer (2020) that include a better understanding of clouds' effects, suggest a warming of over 5 °C.
- Effects of warming on underlying drivers towards dangerous climate change. For instance, the extreme heat persisting in the Arctic (e.g. over Siberia in 2020) has been conclusively linked with

human-induced warming[4] and is exacerbating warming through extensive forest fires and permafrost melt along with loss of snow and ice cover.

- Atmospheric concentrations of GHGs other than CO_2 are increasing. Jackson *et al.* (2020) report atmospheric methane concentrations of approximately 1875 parts per billion at the end of 2019: over 2.5 times pre-industrial levels, and near the IPCC RCP8.5 scenario that leads to an average warming of 4.3 °C by the year 2100.

- Several of the theoretical scenarios where negative emission technologies are deployed at huge scales to remove CO_2 from the atmosphere, or to intercept solar radiation to reduce radiative forcing, are unproven, logistically implausible or associated with substantial and unquantifiable risks (see, for example, EASAC, 2018, 2019; Barret *et al.*, 2014; NRC, 2015). Progress to develop economic and practicable solutions on the most promising approaches (enhanced weathering (Beerling *et al.*, 2020); direct air capture (see, for example, Realmonte *et al.*, 2019); and carbon capture and storage (see, for example, Lipponen *et al.*, 2017)) is too slow to contribute to avoiding overshoot on Paris Agreement targets. Equally, the technologies capable of utilising gigatonne quantities of CO_2 as a feedstock (ICEF, 2016) remain at the research and development stage, with high energy and cost challenges yet to be overcome (Hepburn *et al.*, 2018).

The UNFCCC had as one of its core rationales the avoidance of 'dangerous climate change'. This arises from positive feedback mechanisms that accelerate warming and lead to non-linear changes in climate change beyond human society's ability to adapt. Possible drivers of such changes include albedo change due to snow and ice loss, release of methane from permafrost and deep ocean stores, and collapse of natural land and ocean sinks through warming. How can such dangers be assessed?

Palaeoclimatology can infer climate conditions over the millions of years at various atmospheric CO_2 levels or average temperatures. Drawing direct analogies is not possible due to the great difference in the speed and origin of the changes to the atmosphere; anthropogenic changes are occurring over decades while the same changes in atmospheric took thousands to hundreds of thousands of years in previous epochs. The response times in land and ocean systems may thus be quite different. Nevertheless, scientists have analysed past climate changes to seek insights into the climate effects of injections of greenhouse gases into the atmosphere.

Of particular interest are the warm periods between the ice ages (Eemian), the Pliocene (2 million to 3 million years ago when CO_2 concentrations were similar to those currently and average temperatures were around 3 °C above pre-industrial levels (Haywood, 2019)) and the Palaeocene–Eocene Thermal Maximum (PETM) when average global temperatures rose 9–12 °C about 55 million years ago.

As described in Box 2, records show the non-linearity of the climate system and indicate the need for extreme caution in applying linear models to predicting impacts over more than the immediate short term. Indeed, looking into the past suggests that there may not be

Box 2 Palaeoclimate insights

In looking at the potential impacts of human-caused climate change that is already shifting from the Holocene to the Anthropocene epochs, the Eemian period was the most recent when global temperatures were similar to those of today and sea levels 5–7 metres higher. The Pliocene epoch also had atmospheric CO_2 levels similar to today of 427 p.p.m. 3.3 million years ago, when temperatures were 3–4 °C hotter and sea levels were at least 20 metres higher (de la Vega *et al.*, 2020).

For an example of an even warmer climate, the PETM has been much studied, when CO_2 levels were above 600 p.p.m. With the current level at 418 p.p.m., rising at 2–3 p.p.m. per year, 600 p.p.m. could be reached within the lifetimes of today's children if unconstrained. At this rate of increase, Hansen *et al.* (2016) calculated a potential for 4–7 °C warming by 2100 when atmospheric concentrations would be between 700 and 1000 p.p.m. CO_2.

With business-as-usual taking us to levels of CO_2 experienced at the PETM, it may be relevant to examine the nature of the mass extinctions that occurred. Here, two processes in the oceans were critical. First, the effects of temperature increase, which led to anoxic oceans (warmer waters hold less oxygen and related algal blooms deplete oxygen when they degrade). Secondly, acidification, which impeded shell and skeleton formation. Ultimately, the anoxia generated highly toxic hydrogen sulfide and extended mortalities to land species, as well as depleting the ozone layer, causing genetic damage to the species that survived. The PETM with its eventual warming of 9–12 °C above the 1880s average represents an extinction event for marine and terrestrial life and clearly would have been incompatible with human life as well. Of course, such changes took place over many thousands or hundreds of thousands of years, but the current human-derived rate of increase is many times faster than in periods such as the PETM, and may trigger the release of carbon stocks stored in permafrost and methane hydrates in deep waters at a faster rate.

[4] https://www.worldweatherattribution.org/siberian-heatwave-of-2020-almost-impossible-without-climate-change.

stable climate states at just any temperature and that the Earth may 'switch' from one semi-stable state to another: in other words, proceed in step changes rather than smooth transitions (Steffen *et al.*, 2018). Further adding to the challenge of properly recognising climate-based threats is that the huge inertia of the Earth's oceans delays and slows changes, rendering them easily overlooked in the short term. Yet current atmospheric concentrations will continue to warm the planet for centuries, and warming effects such as expanding oceans and melting icecaps play out over decades to centuries and are irreversible within human timescales.

2.3 Biodiversity and ecosystem services

Biodiversity underpins the ecosystem services on which many aspects of human well-being depend. International recognition of this is seen through the Convention on Biological Diversity (CBD) in 1993, and IPBES (from 2012). Major reviews of the state of ecosystem services were conducted in the Millennium Ecosystem Assessment (MEA, 2005) and most recently in the *Regional Assessment Report on Biodiversity and Ecosystem Services for Europe and Central Asia* (IPBES, 2018) and the *Global Assessment Report on Biodiversity and Ecosystem Services* (IPBES, 2019). Since those comprehensive reviews, scientific papers continue to be published, such as a recent paper on vertebrate extinctions (Ceballos *et al.*, 2020). The 2020 State of Nature report also confirms that biodiversity in the EU continues to decline (EEA Report 10/2020).

As pointed out by IPBES (2019), nature and its biodiversity play a critical role in providing provisioning services of food and feed, energy, medicines and genetic resources, while ecosystem services sustain air and water quality, provide soils, climate regulation, pollination and pest control, reduce impacts of natural hazards, as well as providing cultural services such as recreation, tourism, intellectual development and spiritual enrichment. The value of these services is difficult to quantify but critical. For example, 75% of global food crops depend on animal pollination; and marine and terrestrial ecosystems sequester 5.6 gigatonnes of carbon per year (60% of global anthropogenic emissions). Many ecosystem services are in decline; for instance, soil organic carbon, pollinator diversity, land productivity, coastal habitats and coral reefs, while two-thirds of the ocean area is degrading through overfishing, nutrient inputs, warming and pollution. Thirty-two million hectares of primary or recovering forest were lost between 2010 and 2015, and rates of deforestation continue unabated or are even increasing (IAP, 2019).

IPBES points out that nature is essential for achieving the SDGs and that current negative trends in biodiversity and ecosystems undermine progress towards 35 out of the 44 assessed targets of SDGs related to poverty, hunger, health, water, cities, climate, oceans and land (SDGs 1, 2, 3, 6, 11, 13, 14 and 15). Examples of declines in nature and the direct and indirect drivers are shown in Figure 5.

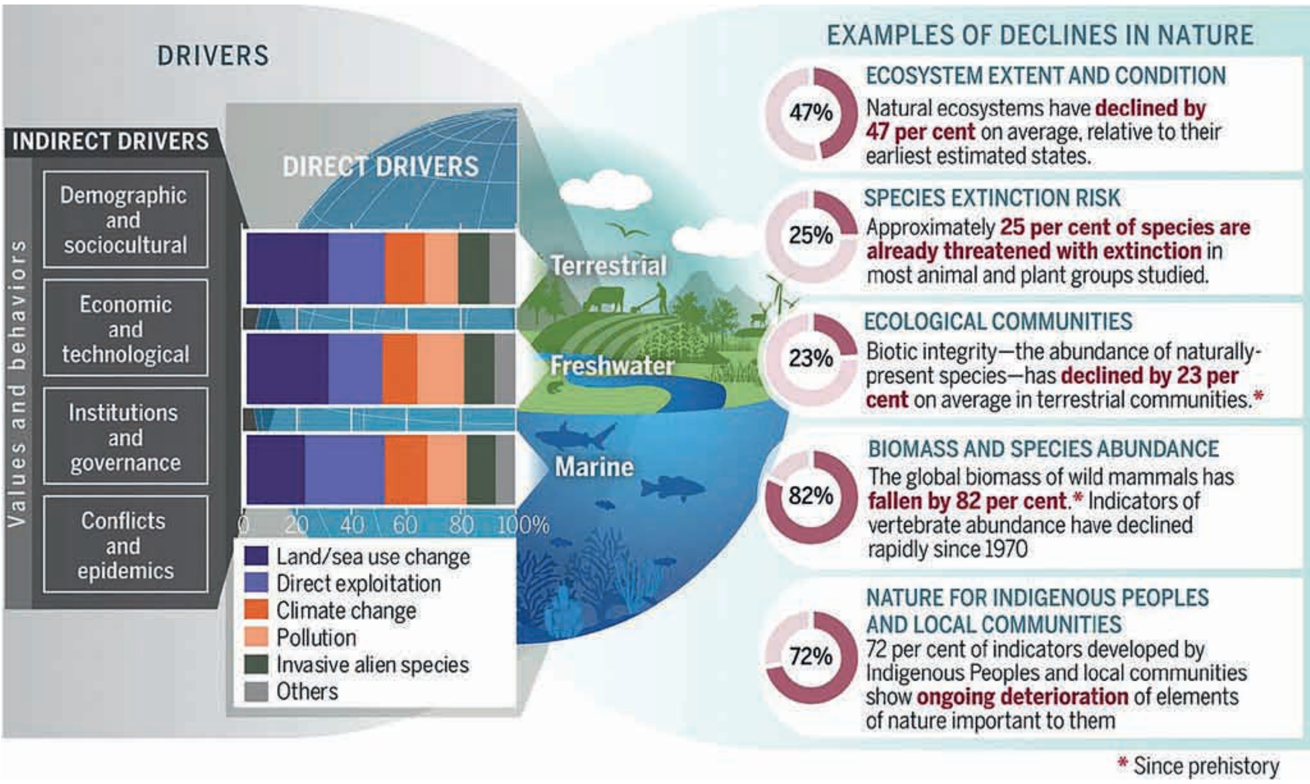


Figure 5 Examples of global declines in nature, and direct and indirect drivers of biodiversity loss. Source: figure 2 in IPBES (2019).

Biodiversity loss indicators comprise both declines in the numbers of individuals within a species and complete loss of species through extinction, both of which are accelerating owing to continued growing anthropogenic pressures on the biosphere. As pointed out in IPBES (2019), the Living Planet Index (www.livingplanetindex.org) shows rapid declines since 1970 in vertebrate populations (40% for terrestrial species, 84% for freshwater species and 35% for marine species). Human actions have already driven at least 680 vertebrate species to extinction since 1500, and around 25% of animal and plant species are threatened with extinction if current trends are not reversed. Agricultural expansion is the most widespread direct driver of habitat loss, together with a doubling of urban area since 1992 and associated expansion of infrastructure. Other threats include water extraction, exploitation, pollution, climate change and invasive species. Extinctions affect the functional units, redundancy, genetic and cultural variability in ecosystems and undermine the life support conditions on which humanity depends. As with climate change, there may be a delay between habitat loss and extinction of individual species (an extinction debt), and reversing these trends may be impossible even if habitat is restored (see, for example, Kuussaari *et al.*, 2009).

The negative trends in biodiversity and ecosystem functions are projected to continue or worsen in future scenarios in response to continued population growth, unsustainable production and consumption and associated technological development. This led IPBES and others to conclude that goals for conserving biodiversity and achieving sustainability cannot be met by current trajectories, and biodiversity goals for 2030 and beyond may only be achieved through transformative changes across economic, social, political and technological factors. As shown in Figure 5, several direct and indirect drivers underly current unsustainable development. A detailed review of all these drivers is beyond the scope of this overview but there are two aspects that feature often in related debates: the role of population and underlying economic systems. Some comments are thus provided on these two aspects.

2.4 Population and consumption

As long ago as the 1970s, Ehrlich and Holdren (1971) introduced the formula $I = PAT$ to approximate the environmental impact (I) of population (P) and consumption (A is affluence) through their combined demand for energy and resources. Technology (T) is capable of offering mediation (e.g. improved efficiency) or amplification (e.g. increasing demand through new markets) on the basic formula.

Although this is only a very rough approximation of reality, it does help illustrate why environmental impact has ballooned in the period since the Second World War. Then, global population was around 2.5 billion and total energy consumption just under 20,000 terawatt-hours; since then, population has increased by a factor of 3 and global energy consumption increased to over 150,000 terawatt-hours (a factor of over 7). Taking GDP per capita as the approximate measure of A, this has increased from US$3,277 in 1950 to US$14,574 in 2016 [5], an increase of around 4-fold. Before considering the impact of technology therefore, impact (I) has increased by a factor of 12. The technological improvements in energy and resource efficiency have offset some of this (for example, the same GDP in 1992 and 2003 was achieved with 20–30% less energy and materials) but this has been wholly insufficient to compensate for continued growth in population and GDP. Moreover, the differences in affluence (A) both between and within countries are huge so that the impact of an individual's lifestyle can vary by several orders of magnitude[6].

Fertility rates have declined in many countries – the so-called demographic transition – and current population forecasts from the UN (Figure 6) are that the global population will be between 9.4 billion and 10.1 billion in 2050, and between 9.4 billion and 12.7 billion in 2100 (UN, 2019). Although fertility rates are declining, the UN's review points to the challenges facing some countries and regions related to rapid population growth driven by continued high fertility.

Changes in diet are also relevant to Ehrlich's earlier formula. As standards of living increase and consumers switch from plant-based protein to animal protein, the environmental impact of food increases. For instance, Scarborough *et al.* (2014) calculated that each kilogram of beef requires 163 times more land use, 18 times more water use, 19 times more nitrogen and emits 11 times more CO_2 than 1 kilogram of rice or potatoes. In terms of dietary choices, Bingli *et al.* (2019) point out that demands from a non-vegetarian diet exceed those from of a vegetarian diet by substantial amounts: for water 2.9 times, primary energy 2.5 times and fertiliser 13 times. Livestock farming (meat and dairy) uses 70% of agricultural land overall and thus plays a major role in CO_2 release and biodiversity loss from deforestation. Bingli *et al.* conclude that a vegan diet has the lowest

[5] https://ourworldindata.org/grapher/average-real-gdp-per-capita-across-countries-and-regions?time.

[6] For instance, the average GDP per capita in Qatar (US$117,000) is 177 times that in the Central African Republic (US$661). Within one country (USA), the wealth of the richest individuals is over US$100 billion whereas the US Federal Poverty guidelines of US$12,760 for one person apply to 38 million. https://ourworldindata.org/global-economic-inequality.

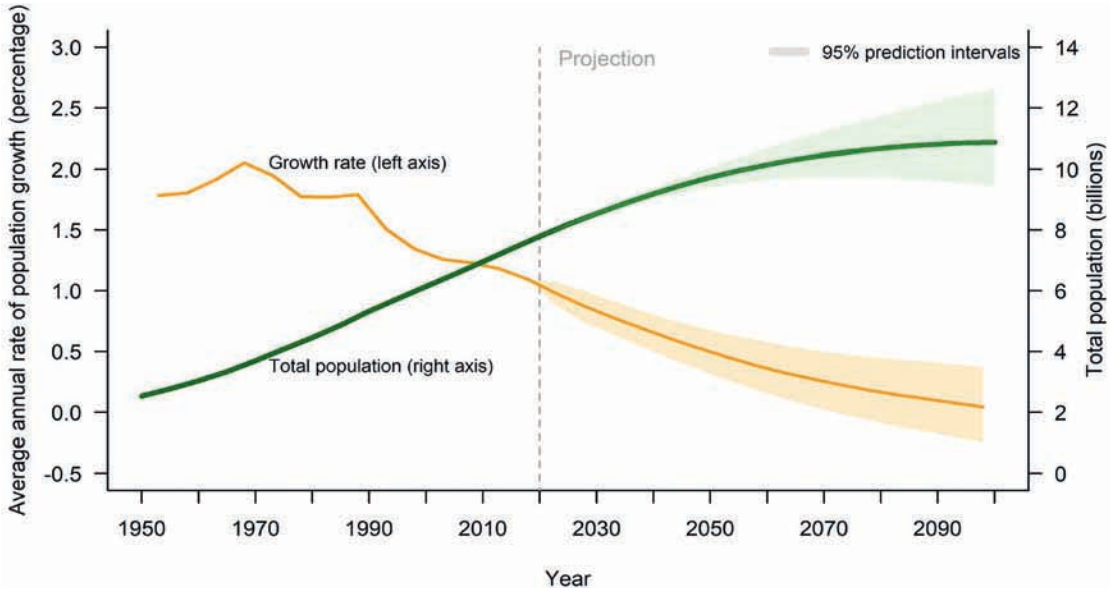


Figure 6 Population size and annual growth rate for the world (UN, 2019).

environmental impact, but substantially reducing meat and dairy food in a non-vegetarian diet can also lead to similarly low impacts.

Raising population as an issue remains controversial, especially while the environmental impact of each person varies so much. The average American emitted 16.1 tonnes of CO_2 in 2018, and one Australian 16.8 tonnes, while the average Afghan just 0.3 tonnes. Differences between income groups are stark, with Otto *et al.* (2019) finding that a typical super-rich household of two people produces a carbon footprint of 129.3 tonnes of CO_2 equivalent per year. Other estimates suggest the average emissions of someone in the top 1% of the global income bracket emits 175 times that of someone in the poorest 10% (Oxfam, 2015). As noted by Wiedmann *et al.* (2020), '*The affluent citizens of the world are responsible for most environmental impacts and are central to any future prospect of retreating to safer environmental conditions*'.

From a scientific perspective, therefore, the size of the global population needs to be considered alongside per capita consumption of resources in assessing future environmental sustainability. One of the objectives of sustainable development is to provide the poorest people with a healthier, safer life and higher standard of living, which is inevitably associated with an increase in their per capita emissions (Barrett *et al.*, 2020). Consumption by the rich will thus need to give way if such objectives are to be achieved within planetary boundaries. Even so, the total number of people still matters and continuing high fertility rates make achieving the SDGs more intractable. As noted by Naidoo and Fisher (2020), '*if the world's population rises, as predicted, to 9.7 billion by 2050, it will exacerbate all other threats to sustainability*'. Meeting the SDG of empowering women and educating girls is thus highly relevant to achieving other SDGs (Barrett *et al.*, 2020). Indeed, Vollset *et al.* (2020) calculated that achieving the SDG targets for education and contraception would result in a more sustainable global population of 6.29 billion by 2100.

2.5 Economics' compatibility with sustainable development

Current economic theories evolved following the Industrial Revolution when environmental and resource pressures were local and did not stretch global boundaries. Such impacts were able to be treated as external to the developing theories of supply, demand, markets, trade within and between countries, labour, capital and so on. It has long been recognised that this leads to incorrect pricing signals and market failures, and that these have become increasingly important as human impacts on the environment and resources at the planetary level have increased. These fundamental shortcomings have been widely recognised, but have not yet been addressed in individual decision-making between stakeholders, nations or international organisations. Many books have been written on these aspects which are beyond the capacity of this overview, but some of the aspects that are particularly relevant to sustainable development are highlighted.

2.5.1 GDP as an indicator and GDP growth as a policy objective

The inherent strengths and weaknesses of GDP have been debated almost since it was adopted as the international standard for measuring economic progress in the aftermath of the Second World War. Even before its adoption, its author (Simon Kuznets) had pointed out it was not for measuring social well-being: rather, on the basis of market transactions, it merely provides a monetary measure of the value of all final goods and services produced in a given period of time. By such a direct link with consumption, GDP essentially equates value with exploitation of natural resources. It does not take into account social costs, income inequality, environmental impacts and the state of global and regional ecosystems (including climate). Nor does it measure social interactions such as parenting, household or volunteer work. Despite this, GDP remains the headline indicator against which the performance of economies tends to be assessed and political priorities set.

Many attempts have been made to design an indicator capturing social and environmental trends (see, for example, Asheim, 2011; EASAC, 2016). As pointed out by Stiglitz *et al.* (2009), there are two aspects to this debate. Firstly, well-being assessment involves non-economic aspects of peoples' lives (e.g. health and quality of personal life, the natural environment in which they live). Secondly, it involves inter-generational sustainability (whether levels of well-being can be sustained over time), which depends on whether stocks of capital that matter for our lives (natural, physical, human, social) are passed on to future generations.

One of the most readily recognised shortcomings of GDP is that it does not take into account the costs of side-effects of economic activities (negative externalities). Thus, remedial measures following catastrophes such as the Fukushima disaster in Japan, the Deepwater Horizon spill in the Gulf of Mexico and damage from hurricanes all contribute positively to GDP. Moreover, it treats equally activities to which society associates positive (e.g. building a hospital or school) and negative (e.g. criminal activities) values. Some activities (e.g. volunteering) and personal conditions (e.g. being healthy) with a positive social recognition are not taken into account. Another essential shortcoming of GDP is that it bases its calculations on the flow of resources whereas from a sustainability perspective, the stock of capitals (whether man-made, social, human or natural capitals) available for the provision of human well-being is important.

Many alternative measures of progress have been devised. Some of them (the Index of Sustainable Economic Welfare and the Genuine Progress Indicator) adjust GDP to incorporate social and environmental factors: for example, the benefits from volunteer work, the costs of divorce, crime and environmental pollution. GDP and the Genuine Progress Indicator per capita of 17 considered countries have shown a divergent trend since the 1970s (Figure 7).

The Index of Sustainable Economic Welfare and the Genuine Progress Indicator are the two primary candidates for a replacement but still depend on flows and cannot provide an indicator of how far well-being can be maintained. An attempt to integrate current and future well-being is in the **Inclusive Wealth Index**, which measures wealth using countries' natural, manufactured, human and social capital (e.g. Polasky *et al,* 2015). Research continues to develop an ideal indicator of social welfare- such as through the European Commission's *GDP and Beyond: Measuring Progress in A Changing World* initiative (EC, 2009).

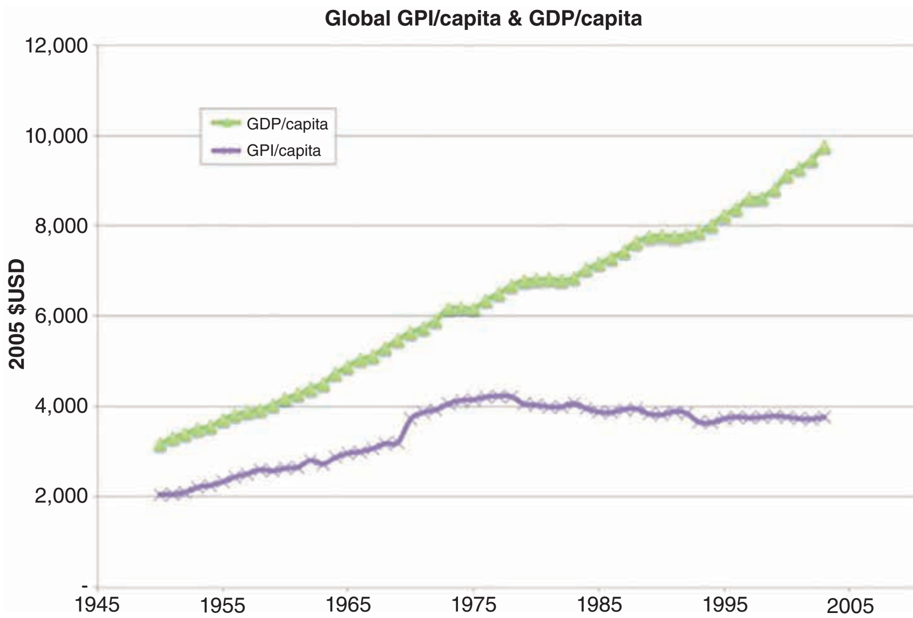


Figure 7 Divergence of trends in GDP and the Genuine Progress Indicator across 17 countries (after Kubiszewski et al., 2013).

2.5.2 Cost–benefit analysis and the discount rate

Many decisions on development include calculations of the costs and benefits. This requires a means of valuing a benefit which may only arise in the future against costs that have to be incurred now, and is meant to reflect people's preferences between future and current consumptions. Such calculations involve a social discount rate to reflect the degree to which future values are discounted in order to make objective comparisons with current values. There is a built-in assumption of continuity on the economic system with technological progress continuing and the environment remaining stable in such calculations. When considering the effects decades (or centuries) into the future of current actions, the discount rate selected is a critical determinant, and the appropriate rate remains a matter of debate. Establishing an objective or 'true' discount rate is complicated by, for example, differences in people's preferences and in the amount of growth expected in the future. There are also arguments for using different discount rates for decisions in the short term (e.g. for building a road or school) and those in the long term (e.g. for mitigating climate change for centuries to come) — a variable rate.

Typically, figures of a few per cent or as high as 7–8% are used[7]. A discount rate of 7% means that the value to the present of damage avoided in 50 years' time is essentially zero; at a rate of 4%, it is just 14.5% of the saving; and at 1%, 60%. In this way, the economic justification for an investment now based on avoiding future damage or providing future benefits can become very subjective: by choosing a high discount rate, it becomes more difficult to justify expenditure. The resulting subjectivity is seen in positions taken by different economists (Gollier and Hammitt, 2014; Millner, 2020). Thus, those opposing investment in climate change mitigation may argue for rates of 7%, while those supporting early action will favour low rates (e.g. the 1.4% rate used in the seminal report by Stern (2006)). A survey of 200 economists in 2015 showed that the vast majority thought a rate between 1% and 3% was appropriate (Drupp *et al.*, 2018). Adopting a low (sustainable) discount rate substantially increases the willingness to pay of stringent emission reductions (Dietz and Asheim, 2011).

A high discount rate suggests that those alive today are worth much more than future generations, and prioritises current wins over future costs. This therefore fails the intergenerational equity requirement of sustainable development (Krznaric, 2020). Rather, an ethics-based approach based on inter-generational justice (see Gosseries and Meyer, 2009) would argue for a very low, zero or even negative rate (to reflect the expectation that there will be more people in the future among whom resources have to be shared). Reaching an objective value is attempted in IPCC calculations and is included in its integrated assessment models that assess economic effects of different emission scenarios. However, such calculations are based on largely linear assumptions on the future growth of the economy and of climate impacts, and are unable to factor in non-linear or local/global catastrophic impacts (see later). It is thus not possible to exclude ethical factors in deciding the rate under which policy proposals are assessed.

2.5.3 Placing an economic value on environmental impacts

While people may attach non-monetary values to the environment (aesthetic, cultural, ethical, etc.), development decisions are guided by economic assessments of costs and benefits, where environmental side-effects need to be expressed in monetary terms. This is the field of environmental economics which, since the 1970s, has sought means of factoring into economic decision-making, environmental and social effects. Some progress has been made in factoring local, short-term environmental impacts (see, for example, Hoel, 2004), but non-local issues such as climate change and global ecosystems remain at the research stage. A UN-supported programme (The Economics of Ecosystems and Biodiversity) continues and many case studies have demonstrated that developments that are economic in traditional cost–benefit terms became counterproductive when associated damage to longer-term ecosystem service values were included. Other researchers have attempted to quantify the monetary value of global ecosystem services (see, for example, Constanza *et al.*, 1997), assigning values that are a significant proportion of global GDP to un-costed and taken-for-granted services. Work continues to develop methods for and calculations of the value of ecosystem services in countries' national capital accounts (e.g. Stanford University's National Capital Project; Bateman *et al.*, 2014; Bateman and Mace, 2020). However, these have not yet reached a sufficient consensus to build into short-term economic and political decision-making.

One of the approaches in this category currently applied in the context of climate change is to price carbon, as summarised in Box 3.

From the figures in Box 3, it is apparent that carbon pricing is not yet comprehensively applied; nor are the rates anywhere near either the scale of fossil fuel subsidies or the price per tonne required to mitigate climate change. With the limited coverage and vast

[7] https://www.lse.ac.uk/granthaminstitute/explainers/what-are-social-discount-rates/.

Box 3 Pricing carbon

A simple means of bringing down emissions from carbon-based fuels, and driving investment into cleaner (zero or low-carbon) alternatives, is to place a price on carbon. There are two main methodologies available. A **carbon tax** is a levy on the carbon content of fuels, thus raising their price when used in transport, energy and industrial sectors; such taxes apply in 29 countries (World Bank, 2019). The other means is to place a **cap on carbon emissions**, and auction permits to emit. Polluters can trade their permits with others, so that those with excess permits can sell to those with insufficient permits — thereby creating a financial incentive for emission reductions. The European Union Emissions Trading System is the largest example, introduced in 2005. Since then, the price of CO_2 has ranged from near zero to around €30 per tonne. At the global level, the UNFCCC's Clean Development Mechanism has failed to establish a viable carbon price and crashed to less than €1 per tonne of CO_2 in 2012. The reduced demand for energy following the COVID-19 pandemic has also led to a collapse in Emissions Trading System prices.

There are many economic aspects in the design and use of income from such schemes, but the question from the point of view of climate change mitigation is their effectiveness in reducing emissions. One means of assessing their significance is to compare incomes from carbon pricing with those estimated to be required to meet Paris Agreement targets. Here, the IMF (2019) considers that the carbon price needed to comply with the upper bound of Paris Agreement targets is US$75 per tonne of CO_2 by 2030. In contrast, the World Bank survey showed that in the countries applying such taxes, prices ranged from near zero to US$139 per tonne of CO_2. Overall, pricing was applied to just 20% of global GHG emissions. Carl and Fedor (2017) estimated global income from carbon pricing was US$28.3 billion collected annually in 40 countries and 16 states or provinces around the world. In contrast, the global subsidies for fossil fuels were estimated by the IMF (2019a) at US$5.2 trillion in 2017 (6.4% of GDP): US$500 billion to reduce the retail price of fuels, and the rest the costs of warming caused by fossil fuel emissions which are not borne by the industry.

differences in fees, carbon pricing also raises substantial economic questions. Firstly, there is the national policy on how to manage tax income and associated effects on prices and other sources of tax revenue. Second is the effect that regulation of emissions in one country/sector has relative to other countries/sectors that are not subject to the same regulation. Differences may lead to competitive losses, shifts of emitting industries to zero pricing areas, requiring international negotiations on border tax adjustments, trade tariffs and trade bans. These are not discussed here, but it can be seen that the potential effectiveness of carbon pricing cannot be judged from the weak and limited experience to date. It remains a simple and effective fiscal tool with which to combat climate change and remain within planetary boundaries (Parry, 2019; Engström *et al.*, 2020).

2.5.4 Dealing with non-linearity of climate change

Policy decisions tend to assume that changes to the economic system will be linear and non-linear effects (such as the financial crash of 2008) rare. The same assumptions may also underly attempts to quantify the economic effects of climate change. As summarised in section 2.3, however, geological records show the extreme non-linearity of the climate system and indicate extreme caution in applying linear models to predict impacts over more than the immediate short term.

An example can be provided by the work receiving the 2018 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel (Nordhaus, 2018). This developed a 'Dynamic Integrated Model of Climate and the Economy' (DICE) to account for the interactions of labour, capital, interest rates, etc., in a warming climate. This allowed GDP loss to be calculated and related to temperature which was then compared with the costs of mitigation and adaptation. In the presentation to the Prize-giving ceremony, an 'optimum' balance between costs and benefits was shown to be a trajectory where average global temperature increases stabilised at 4 °C above pre-industrial levels in 2140. Included in this study were estimates of GDP loss for temperature rises between 1 and 10 °C (2 °C: <1%; 4 °C: 3.6%; 10 °C: 23%).

Yet the palaeoclimate record (Box 2) shows that, well below 10 °C warming, the Earth would become uninhabitable: a loss of 100% GDP (along with humanity). Even temperature increases associated with the IPCC RCP8.5 scenario, which calculates an average warming of 3 °C by 2070, would expose around 30% of the global population to mean annual temperatures exceeding 29 °C — currently experienced by only 0.8% of the population near the Sahara (Xu *et al.*, 2020) and too severe for human tolerance when in humid areas (Raymond *et al.*, 2020).

Other economic models do attempt to factor in non-linear effects and find that the optimal carbon tax should be between 50% and 200% higher than recommendations without tipping points (Lontzek *et al.*, 2015; Cai *et al.*, 2015; 2016). Lemoine and Traeger (2016) investigated the impact of multiple tipping points that trigger each other and also arrive at the conclusion that much more stringent climate policy is required. Other researchers (Van der Ploeg and de Zeeuw, 2016; 2018; 2019) looked at what happens where regions with different economic characteristic do not manage to cooperate around a common policy.

Climate effects also interact with socio-political trends in a non-linear way. One example is the continued high rates of population growth in parts of the world particularly vulnerable to climate change, driving both internal and cross-boundary migration. In this context, the World Bank (Rigaud *et al.* 2018) estimated internal migration (largely from rural to urban areas) as a result of natural disasters and general temperature and rainfall trends. Within the most sensitive areas in sub-Saharan Africa, South Asia and Latin America, 143 million people are projected to move by 2050 within their own countries. Movements on such a scale add to those forced to move owing to sea-level rise (Hauer *et al.*, 2020) and add to pressures for migration across borders.

Economic calculations that avoid non-linear effects (tipping points) can reassure many that climate change is easily managed and requires limited actions by current generations[8].

A similar criticism applies to the IPCC integrated assessment models (Pindyck, 2017). It is important that policymakers seek the more complex models when assessing the economic impacts of climate change, including those that explore detailed approaches to implementing a carbon tax in different regions (Brock *et al.*, 2014). It is also possible now to make good use of the increasing capabilities of climate change attribution where costs can be attributed to the damage resulting from climate change. For instance, Frame *et al.* (2020) found that, of the damages from Hurricane Harvey of US$90 billion, one-third to three-quarters (a best estimate of US$67 billion) could be attributed to the human influence on climate. Such evaluations of the costs of extreme weather resulting from climate change are now widely available and contrast sharply with the more ‘top-down’ approach using integrated assessment models or global macroeconomic estimates. The consequence is that economic evaluations need to be much better integrated with climate science if proper risk assessments are to be available to policy-makers[9].

2.5.5 Energy and resource decoupling

Since concerns started to be expressed over limits to growth due to resource constraints, the concept of ‘decoupling’ has been seen as a possible route to a sustainable form of economic growth. The concept can be expressed as ‘getting more from less’: ultimately ‘decoupling’ environmental impacts and resource demands from their historical correlation with GDP growth. The OECD (2002) defined the term as breaking the link between ‘*environmental bads*’ and ‘*economic goods*’, but the concept can be traced back much earlier[10]. As part of this, studies into achieving step jumps in the efficiency with which resources and energy are consumed (‘Factor 4’ from von Weizsäcker *et al.* (1998) and ‘Factor 10” from Smidt-Bleek (http://www.factor10-institute.org/pages/factor_10_institute_2008.html)) laid out the potential for new technologies, policies and manufacturing processes together with socio-cultural change to provide a sustainable global economy.

Decoupling is part of the green growth narrative — for example, in the OECD’s strategy *Towards Green Growth* (2011) and the current EGD’s target of an economy where ‘*economic growth is decoupled from resource use*’. Major international reviews took place through the UNEP and its International Resource Panel (IRP) (see, for example, UNEP, 2011; 2016; 2018). The ideal is that decoupling environmental pressures from GDP could allow future economic growth without end.

To achieve this, however, decoupling would have to overcome the persistent and opposite trends in consumption. For instance, during the 20th century, the extraction of construction materials grew by a factor of 34, ores and minerals by a factor of 27 and fossil fuels by a factor of 12 (Krausmann *et al.*, 2018). Between 1970 and 2017 (IRP, 2019), consumption rose by factors of 2.7 for biomass, 3.5 for metals, 2.5 for fossil fuels and 4.9 for non-metallic minerals. To assess decoupling’s performance and potential, key indicators (see EASAC, 2016) include carbon and other emissions, material and other resource consumption per unit of GDP output, which may be expressed in terms such as ‘eco-efficiency’ and ‘resource productivity’.

There are two types of decoupling. **Relative decoupling** is where environmental impact and resource consumption rise at slower rates than GDP (improved resource efficiency/productivity). But to reduce impacts overall (**absolute decoupling**), eco-efficiency improvement must always outpace GDP growth. As long ago as 1991, Daly (1991) noted, while relative decoupling can be shown to have occurred, this is generally without absolute decoupling taking place[11].

[8] For example, Nordhaus’s work has been used to suggest that only limited economic measures (such as a moderate carbon tax) are sufficient to combat global warming: https://www.wsj.com/articles/u-n-ignores-economics-of-climate-1539125496.
[9] The growing field of ‘complexity science’, which seeks to overcome the limitations of simplistic linear thinking, has a role to play (Miles, 2009). This seeks to overcome the reductionism inherent in science and economics education at the expense of horizontal (holistic) approaches, by analysing the complex, dynamic and interconnected relationships that are occurring in issues such as climate change or public health issues such as obesity.
[10] For example, the World Business Council for Sustainable Development used the term ‘eco-efficiency’, which allows human needs to be met while reducing environmental impacts and resource demands (Schmidheiny, 1992).
[11] From 1900 to 1969, the amount of materials used to generate a dollar’s worth of GNP halved, but total materials consumption increased by 400%.

More recent studies have shown the extent to which even relative decoupling has slowed or reversed. For instance, when the whole production chain is considered in global markets, Wiedmann *et al.* (2015) showed that much of the apparent decoupling in high-income economies was due to the shift of production to developing countries. A recent review (Parrique *et al.*, 2019) examined the extensive literature on consumption of materials, energy, water, greenhouse gases, land, water pollutants and biodiversity loss and their link with GDP. They found evidence of decoupling but it was mostly just relative (not absolute). In cases where absolute decoupling had been observed, it was only for a short time, concerned only certain resources or specific types of environmental impact, or it occurred only in specific locations. Even where absolute decoupling occurred, it was insufficient to ensure local or planetary boundaries were not exceeded (Raworth, 2018; Parrique *et al.*, 2019).

Parrique *et al.* (2019) also pointed to trends that run counter to decoupling:

- trends to lower grade ores and fossil fuel reserves requiring increased energy and material costs for extraction and purification;
- rebound effects where efficiency improvements lead to increased consumption;
- new demands for resources/energy from new technologies;
- increased material demands for services;
- inherent limits on recycling due to economic, logistical, energy and quality constraints.

In conclusion, while decoupling remains a popular concept to justify the current GDP-based growth model of economic development, the limited impacts of relative decoupling and weak evidence of any absolute decoupling suggest that its potential is limited within current socio-economic systems. Decoupling may offer many good opportunities but these require a more supportive policy framework to achieve them. Achieving decoupling may require a move away from measures that express welfare in material goods production like GDP (section 2.5.1) to indicators where progress does not imply natural resource consumption (Kubiszewski *et al.*, 2013).

2.5.6 Finance

Whether in the context of the EGD or transformative change, implementing the necessary shifts in priorities requires investments. Global investments (public and private) in energy have shown substantial growth in renewables over the 2010–2019 decade but clean energy investments still constitute less than 40% of the total energy-related investments (IEA, 2020). Moreover, the IEA (2020) projects on the basis of tracking company announcements and investment-related policies that there will be a decline in renewable energy investment from US$311 billion in 2019 to US$281 billion in 2020 and barely half of that required in the IEA's scenario for sustainable development.

In the private financial sector, various categories of sustainable or green investments have emerged, but there are concerns that progress towards 'green' industries and away from 'brown' industries continues to be slow and likened to a niche market approach[12]. Indeed, questions remain over whether so-called 'sustainable' or 'green' financing is any more than re-labelling of investments that would have happened anyway, and attempts to answer such questions are hampered by inconsistency in definitions and lack of transparency about how such funds are used and the criteria involved (WRI, 2019). Meanwhile, despite statements of support for a shift in investment priorities towards a sustainable economy, investments in fossil fuels alone remain high. For instance, comparing the WRI's estimate of banks' sustainable finance commitments from 2018 (US$292.3 billion) with the Rainforest Action Network's (2020) data on fossil fuel financing from the top 33 banks alone (US$654 billion) shows that priorities on 'brown' industries remain high. Other surveys show that sustainability issues remain off the radar of many decisions: for example, banks continue to finance companies that are driving deforestation in the Amazon to produce beef, soy, timber and leather[13]. Tensions between financial and climate objectives are increasingly being seen as some government-managed funds seek to reduce investments in fossil fuels and some commercial banks also reduce support for large projects such as Australian coal exports[14].

Initiatives to pressure companies to adopt more aggressive action to cut their emission arise from shareholders and investor groups (e.g. https://climateaction100.wpcomstaging.com/wp-content/

[12] For such views see https://www.euromoney.com/article/b1j97rjr74vd00/sustainable-finances-biggest-problems-by-the-people-who-know-best.
[13] https://amazonwatch.org/news/2019/0425-european-and-north-american-companies-support-those-responsible-for-amazon-deforestation-surge.
[14] Several Western banks have reduced their support of large coal mining and export projects in Australia but funding from Asian banks and private sources have replaced them (see https://www.livemint.com/news/world/here-s-who-s-backing-coal-as-some-of-the-world-s-biggest-banks-get-out-11583712754184.html).

uploads/2019/10/progressreport2019.pdf) and offer an opportunity for governments to support through rules on governance. Ultimately, the rate at which shifts away from support of the 'brown' economy can be accelerated will depend on the financial sector actively supporting the implementation of the EGD and the visions of transformative change. This requires large sources of low-cost finance and long-term perspectives from the industry and its institutional players. The range of measures to develop an EU strategy on sustainable finance is addressing some of these issues[15].

2.5.7 More sustainable economic models

Many economists have researched various aspects of sustainability (for instance on political drivers of unsustainable development) (see, for example, Harstad and Svensson, 2011; Harstad, 2016). Others have focused on the tension between sustainability and short-term efficiency. Resolving this requires a dynamic approach over long time horizons, including complex interactions between different parts of the social-ecological system and uncertainties- instead of the current tendencies in the economy to make decisions on the short run and with limited knowledge (see, for example, Lafuite and Loreau, 2017; Lafuite *et al.*, 2017). Conceptual models have also been advocated in popular books. For instance, Raworth (2012) describes a model aimed at ensuring that everyone on Earth has access to basic needs, such as adequate food and education (the 12 social foundations of the SDGs[16]) while staying within planetary boundaries and thus not limiting opportunities for future generations. This 'doughnut' model is illustrated in Figure 8.

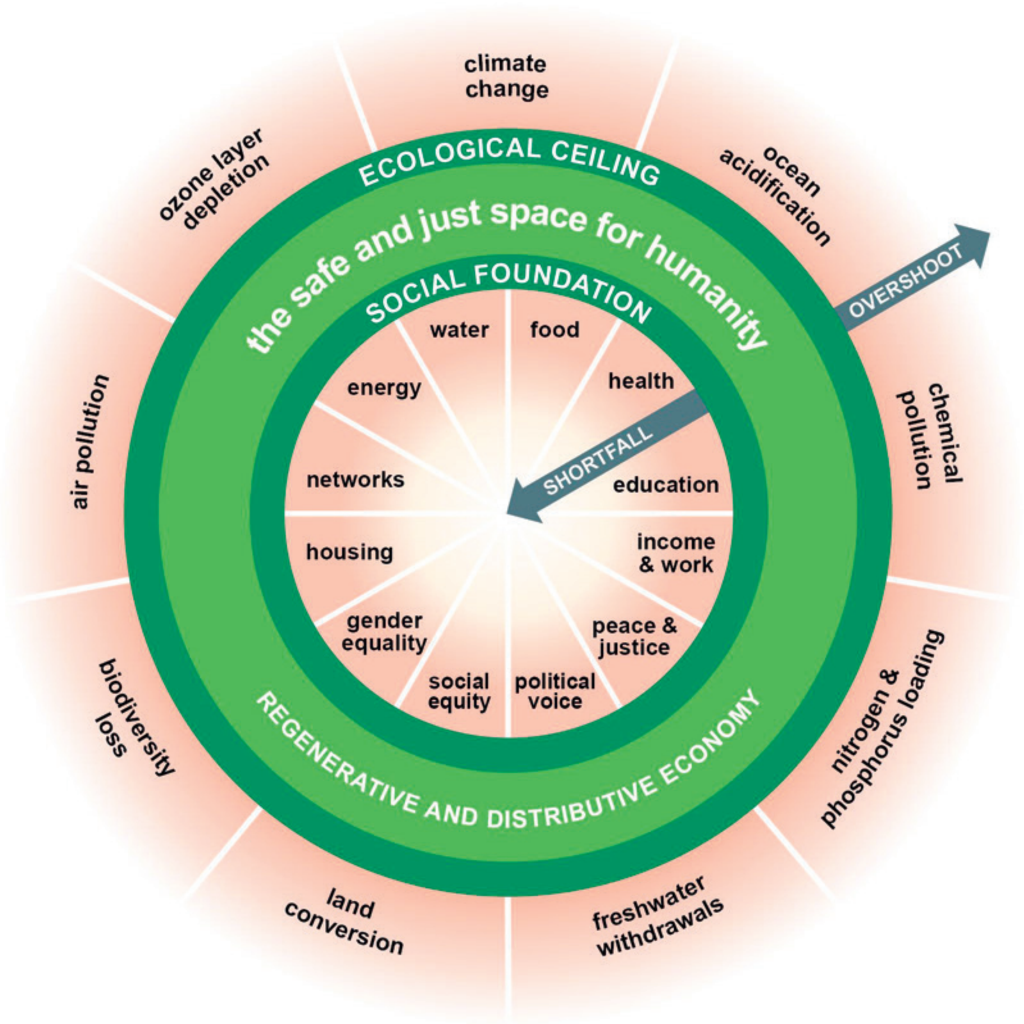


Figure 8 The doughnut economy (after Raworth, 2012). Source: https://en.wikipedia.org/wiki/Doughnut_(economic_model)#/media/File:Doughnut_(economic_model).jpg.

[15] https://ec.europa.eu/knowledge4policy/publication/sustainable-finance-teg-final-report-eu-taxonomy_en.
[16] Food security, health, education, income and work, peace and justice, political voice, social equity, gender equality, housing, social networks, energy, water.

Other work has looked at the failures of economies to reach social objectives. Piketty (2014) points to the rapid growth in inequality since the 1980s, while Jackson (2017, 2018) sees the pursuit of growth at all costs hindering technological innovation, reinforcing inequality and exacerbating financial instability. The dynamics of the existing growth-based paradigm are driving environmental damage, failing to address social inequality and contributing to increased political instability.

Other analyses have shown how relatively simple measures can achieve drastic cuts in CO_2 emissions and meet other major objectives in terms of employment and income. For instance, Hepburn *et al.* (2020) identify five policies with high potential both from economic and from climate impact perspectives: clean physical infrastructure, building efficiency retrofits, investment in education and training, natural capital investment, and clean research and development. Other estimates suggest that simple solutions, if applied globally, can have effective outcomes: as mentioned in section 2.5.3, just the reductions in emissions produced by a US$35 per tonne carbon tax would be sufficient to meet the total commitments of the G20 countries to the Paris Agreement (Parry, 2019).

The limited uptake in economic policy of sustainability-oriented economics may reflect the resistance of political institutions but some economists have suggested that the economics community itself could contribute more. For instance, Oswald and Stern (2019) and Goodall and Oswald (2019) point to the dearth of economics research on key sustainability issues of climate change and biodiversity and conclude that economic research journals could encourage the economic research community to focus on new models that are consistent with a sustainable future; as well as potential for universities and business schools to further adapt basic economics courses to a new sustainability paradigm.

A further generic economic issue is that while the transition to renewable energy must be accelerated, it needs to be efficient: it is no good if producing a new source of energy consumes as much as is produced. A means of assessing this is the ‘energy return on investment’ ratio, which is the ratio of energy output over energy input (Hall and Klitgaard, 2011). Easily accessible fossil fuels had a high energy return on investment ratio of 10 or more (termed ‘high-quality energy’), so the ratio of alternative sources of energy is a factor to be considered in renewable energy policy to inform priorities in investment.

3 What should transformative change involve?

The previous sections summarised the arguments for transformative change: to transition away from patterns of GDP growth, production and consumption that perpetuate deprivations, generate inequalities, deplete the global environmental commons and risk irreversible damage. In this context, the UN Commission on Sustainable Development, the IPBES and others are exploring the conditions under which transformative change could be achieved. Key reports are 'The World in 2050'; the Global Sustainable Development Report; Science for Sustainable Development; Transformations to achieve the SDGs; and IPBES reports. Each of these has described priority points for intervention, target areas for transformation, and policy levers or tools (the terminology varies) where transformative change could lead to a sustainable future. These are summarised in Table 1 and the main points summarised below.

As an example from the studies in the first three columns of Table 1, 'The World in 2050' study states that changes '*… give a people-and-planet-centered perspective for building local, national and global societies and economies which secure wealth creation, poverty reduction, fair distribution and inclusiveness necessary for human prosperity while safeguarding the Earth system*'. It recognises that current unsustainable trends are '*driven by long-term, path dependent second-order dynamics which are deeply embedded in our societal structures, have many feedback and anticipation loops among themselves and will prove extremely difficult to change.*'.

TWI2050 goes on to point out that many of the threats are global yet governments place priority on their own country's interests and may not be motivated to protect the global good. Transformations to sustainable development imply deep structural changes, fundamental reforms of institutions and changing patterns of human behaviour. Incremental change is not seen as able to achieve the degree of changes required so that transformative changes (which may well be highly disruptive) are needed.

Sectors of human activity where transformative changes are required include the following:

- **Consumption and production** are currently associated with excessive use of natural resources and unsustainable levels of pollution, and need to transform towards a circular economy that decreases the amount of resources needed in production systems and also reduces the output in form of pollution and waste. Shifting to more sustainable models of consumption and production requires that we concentrate less on the consumption of resources *per se*, and more on the *services* and *amenities* these help to provide.
- **Decarbonising the world's energy system** requires the replacement of fossil fuels by zero-carbon energy sources such as wind, solar, hydro, geothermal, ocean and nuclear. Long-distance transport of low-carbon energy carriers may use

Table 1 Intervention points, leverage points, transformation targets, policy levers, etc. in different studies

The World In 2050 (TWI2050, 2018)	Science for Sustainable Development (GSDR, 2019)	Transformation to achieve the SDGs (Sachs *et al.*, 2019)	IPBES (2019) and Diaz *et al.* (2019)
Six exemplary transformations: 1. Human capacity and demography 2. Consumption and production 3. Decarbonisation and energy 4. Food, biosphere and water 5. Smart cities 6. Digital revolution	Six entry points: 1. Human well-being and capabilities 2. Sustainable and just economies 3. Food systems and nutrition patterns 4. Energy decarbonisation and universal access 5. Urban and peri-urban development 6. Global environmental commons	Six transformations: 1. Education, gender and inequality 2. Health, well-being and demography 3. Energy decarbonisation and sustainable industry 4. Sustainable food, land, water and oceans 5. Sustainable cities and communities 6. Digital revolution for sustainable development	Eight leverage Points 1. Visions of a good quality of life not entailing ever-increasing material consumption 2. Addressing both population growth and per capita consumption 3. New social norms for sustainability 4. Addressing inequalities 5. Inclusive decision-making 6. Accounting for nature's deterioration from economic activities (inc. international trade) 7. Environmentally friendly technological and social innovation, 8. Education, knowledge generation. including in the sciences and indigenous and local knowledge

hydrogen or synthetic hydrocarbons. Transforming the whole system will include energy efficiency, providing universal access, and reforming electricity grids to accommodate the intermittency of renewables and increase flexibility. Globally, direct and indirect subsidies to fossil fuels still far exceed subsidies to renewable energy which comprise just 20% of all energy subsidies[17]. The resulting distortion of market prices is slowing the diffusion of renewable energy sources. As discussed earlier (Box 3) a carbon tax along with a phasing out of subsidies to fossil fuel could transform the energy system at a relatively small cost, and have positive impacts on all planetary boundaries (Hassler *et al.*, 2018; Sterner *et al.*, 2019; Engström *et al.*, 2020).

- **Food systems and land use.** Today's agricultural systems contribute to climate change and biodiversity loss and are also vulnerable to increased severity of droughts, floods, diseases and land degradation exacerbated by climate change. From the dietary perspective, there is the contrast between some 800 million people undernourished and nearly 2 billion overweight. Transformations of land use and ocean management must thus reduce these negative impacts, make agriculture more resilient to environmental changes and ensure healthy diets (Willett *et al.*, 2019). Restoring degraded ecosystems would store up to 3 billion tonnes of carbon annually. Climate-smart land management practices, including low-emissions agriculture, agroforestry and restoration of high-carbon-value ecosystems such as forests and peatlands, also offer co-benefits. Transitioning to sustainable food systems requires technological innovation, strategic use of economic incentives, new forms of governance and value and behavioural (including dietary) changes.

- **The urban environment.** Projections suggest that the growth in population will be largely in cities, and that the global population living in urban areas will increase from the current 4.2 billion (55%) to 6.7 billion (68%) by 2050. Depending on the planning and policies applied, urbanisation and cities will be either key components of a transition to sustainability or major threats to sustainability (Seto *et al.*, 2017). This is recognised in the reviews in Table 1, where urban (and peri-urban) development is one of the key areas in need of transformation towards smart cities and sustainable means of transport, energy, construction and materials, resilient and sustainable supply chains, etc. And where urban areas make their own contribution to energy (e.g. solar roofs), resources (e.g. water resource cycling) and biodiversity (e.g. wildlife corridors and green spaces).

The IPBES concept of transformation shares the basic principles of the other analyses in Table 1 and concludes that a shift to a sustainable global future requires urgent transformative change: namely a fundamental, system-wide reorganisation across technological, economic and social domains, making sustainability the norm rather than the altruistic exception. IPBES also emphasis the necessity to achieve an absolute reduction in consumption, not just an improvement in efficiency.

IPBES analyses pinpoint five priority **interventions ('levers')** and eight **leverage points**, as illustrated in Figure 9.

The five levers are as follows:

(1) developing incentives and widespread capacity for environmental responsibility and eliminating perverse incentives;

(2) reforming sectoral and segmented decision-making to promote integration across sectors and jurisdictions;

(3) taking pre-emptive and precautionary actions in regulatory and management institutions and businesses to avoid, mitigate and remedy the deterioration of nature, and monitoring their outcomes;

(4) managing for resilient social and ecological systems in the face of uncertainty and complexity to deliver decisions that are robust in a wide range of scenarios; and

(5) strengthening environmental laws and policies and their implementation, and the rule of law more generally.

The eight leverage points are as follows:

(1) enabling visions of a good quality of life that do not entail ever-increasing material consumption;

(2) lowering total consumption and waste, including by addressing both population growth and per capita consumption in different contexts;

(3) unleashing existing, widely held values of responsibility to effect new social norms for sustainability, especially by extending notions of responsibility to include the impacts associated with consumption;

[17] IRENA (2020) estimate the world's total, direct energy sector subsidies at US$634 billion in 2017, dominated by subsidies to fossil fuels, which received US$447 billion (70%). Subsidies to renewable power generation technologies accounted for US$128 billion (20%).

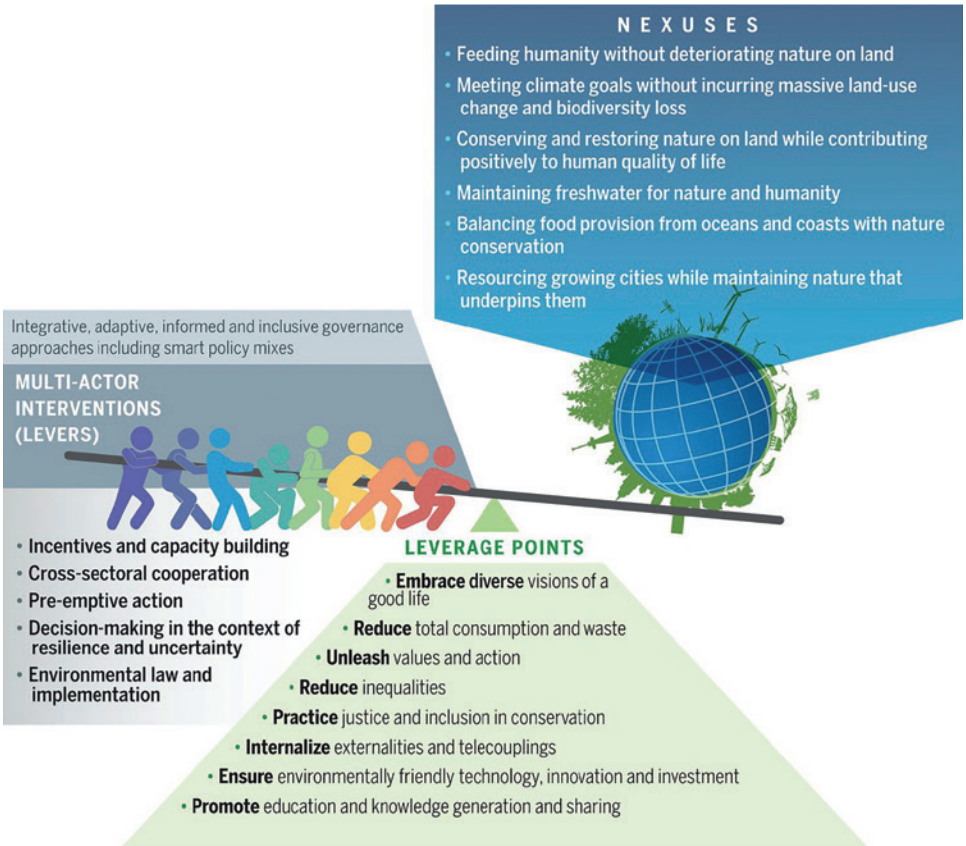


Figure 9 IPBES' (2019) vision of interventions and leverage points for the transformation towards sustainable development.

(4) addressing inequalities, especially regarding income and gender, that undermine the capacity for sustainability;

(5) ensuring inclusive decision-making and the fair and equitable sharing of benefits arising from the use of and adherence to human rights in conservation decisions;

(6) accounting for nature's deterioration from both local economic activities and their distant effects, for example through international trade[18];

(7) ensuring environmentally friendly technological and social innovation, taking into account potential rebound effects and investment regimes; and

(8) promoting education, knowledge generation and the maintenance of different knowledge systems, including in the sciences and indigenous and local knowledge, especially regarding nature, conservation and nature's sustainable use.

Work continues on developing the ideas of transformative change. A recent paper (CBD, 2020) applies the theory of change to transform the current economic, social and financial models to ensure that biodiversity loss will stabilise in the next 10 years and allow for the recovery of natural ecosystems in the following 20 years.

The above reviews emphasise that implementing transformations requires an understanding of the potential pitfalls and sources of resistance to change. The latter include the following.

- Vested interests (e.g. owners of fossil fuels and the beneficiaries of unsustainable land and ocean practices; inertia and resistance to change in sources of investment finance).
- Elite groups; wealth owners are typically resistant to the taxation needed to fund public services and investments. Owners of industries engaged in extractive activities are typically resistant to environmental regulation.

[18] For discussion on the balance between the benefits and costs to the environment of free trade, see Antweiler *et al*. (2001) and Copeland and Taylor (2004).

- The limited capacity of governments to plan and implement policies with timescales of decades[19].
- Difficulties in balancing public private partnerships -especially since the private sector can be captured by vested interests.
- Lack of public understanding and a resistance to change; especially since policies often involve changes in the short term justified by benefits in the longer term.

In the latter context, limited public understanding and public indifference undermine the pressure on governments to act on climate change and biodiversity. There is thus a battle for hearts and minds, which is illustrated by environmental NGO campaigns and by the large investments by fossil-fuel interests in influencing public perceptions of the reality or severity of climate change and its threats.

Transformative change is challenging, since the whole socio-economic system should be changed. To develop it in more detail, the IPBES's second work programme initiated **a thematic assessment of transformative change** whose objective is to '*understand and identify factors in human society at both the individual and collective levels, including behavioural, social, cultural, economic, institutional, technical and technological dimensions, that may be leveraged to bring about transformative change for the conservation, restoration and wise use of biodiversity, while taking into account broader social and economic goals in the context of sustainable development*[20].'

The **WEF** has also been examining from a business perspective the dependence of societies and economies on nature's services. The WEF's long-established global risk assessment has seen a steady increase in the importance given to environmental risk, and in 2020 the top five threats were all related to the environment (climate action failure, extreme weather, biodiversity loss, natural disaster and human-made environmental disasters; WEF, 2020a). Another study (WEF, 2020b) assessed the economic value of nature and its services, and concluded that US$44 trillion (over half the world's total GDP) is potentially at risk from the decline of those services. A separate assessment (WEF, 2020c) concluded that protecting 30% of the planet for nature would generate higher overall output (revenues) than the status quo (an extra US$64–454 billion per year by 2050) owing to the financial impacts of protected areas on the global economy and non-monetary benefits associated with climate change mitigation, flood protection, clean water provision and soil conservation. Such quantitative estimates can provide a useful starting point from which to address the policy paralysis that can result from the uncertainties inherent in tackling the climate and biodiversity crises (Polasky *et al*, 2011; 2020).

The WEF also came to similar conclusions to those in Table 1, namely that addressing climate change was essential but insufficient, and that a fundamental transformation is needed across three major socio-economic systems: (1) food, land and ocean use; (2) infrastructure and the built environment; and (3) energy and extractives. This study (WEF, 2020d) identified 15 systemic transitions in these three sectors (Table 2), with annual business opportunities worth US$10 trillion that could create 395 million jobs by 2030 (Figure 10).

Table 2 Transitions identified by WEF (2020d)

Sector	Transition
Nature-positive food, land, and ocean use system	Ecosystem restoration and avoided land and ocean use expansion
	Productive and regenerative agriculture
	Healthy and productive oceans
	Sustainable management of forests
	Planet-compatible consumption
	Transparent and sustainable supply chains
Nature-positive infrastructure and built environment system	Compact built environment
	Nature-positive built environment design
	Planet-compatible urban utilities
	Nature as infrastructure
	Nature-positive connecting infrastructure
Nature-positive energy and extractives system	Circular and resource efficient models for materials
	Nature-positive metals and minerals extraction
	Sustainable materials supply chains
	Nature-positive energy transition

[19] Even when dangerous trends are recognised, politicians/governments may be unwilling to act because of uncertainties on future projections and because they would be asking citizens to incur short-term costs for (potential) long-term benefits. Policies with intergenerational trade-offs are particularly difficult for governments with a need to be re-elected each 2–5 years.
[20] https://ipbes.net/transformative-change.

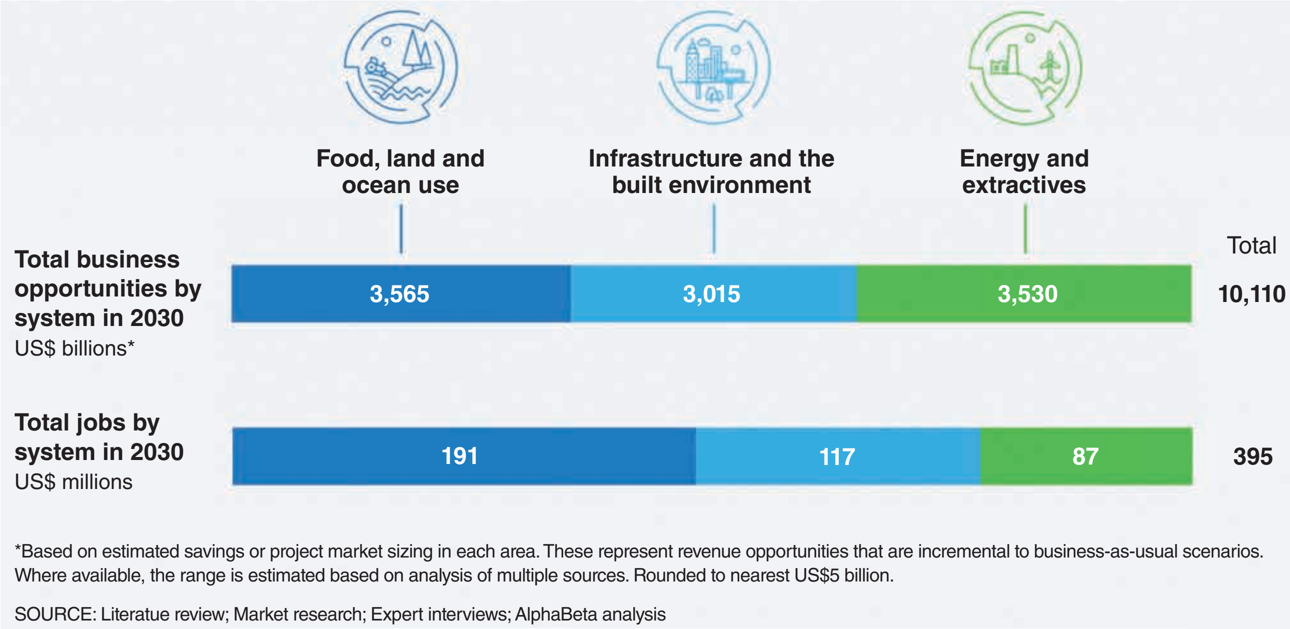


Figure 10 Transitions in three socio-economic systems that could lead to over US$10.1 trillion of annual business opportunities by 2030 (WEF, 2020d).

Echoing the messages in the other analyses, WEF emphasises that a nature-positive, low-carbon and resilient economy cannot be achieved by business action alone. Policy and regulatory change from governments and shifts in the habits and social norms of billions of individuals will be needed to shape the path forward. Business, even if it shares the aspirations of the WEF analyses, cannot proceed without investment and regulations that fully reinforce these trends and redirect the perverse incentives that support 'business-as-usual'. Fundamental structures in incentives that have evolved over the centuries since the Industrial Revolution, based on consumption and GDP-based economic development, currently make destroying nature cheaper than protecting it. As the WEF noted, government subsidies in 2019 exceeded US$300 billion for fossil fuels, and US$700 billion to agriculture of which just 15% was linked to public benefit. Meanwhile US$20 billion a year subsidise overcapacity of fishing fleets leading to unsustainable fisheries. There is thus an urgent need for the business community to work with governments to lay out regulatory pathways that overcome current special interests. Integrated and actionable maps of actions need to be developed to deliver the targets that governments have already agreed under the relevant international conventions on climate change and biodiversity.

4 Points relevant to post-COVID-19 priorities

It can be seen from the previous sections that the calls for transformative change reflect the 'wicked' nature of the challenges faced[21]. Although introduced in the context of organisational management (Rittel and Weber, 1973), 'wicked' problems have come to describe issues including climate change (Stang and Ujvari, 2015) and biodiversity loss (Sharman and Mlambo, 2012). Such 'wicked' characteristics include the following.

- The strong evidence that current paths pose substantial and potentially existential risks to the future is manifested only incrementally and subject to uncertainty.
- Beneficial effects of change are not easily quantified, and often apply in the future beyond the timescales of both individual's and governments' planning and decision-making horizons.
- Adverse trends are inextricably linked to current economic and political systems. Reform of a system that is no longer fit for purpose thus conflicts with some of society's core institutions, making consensus unreachable.
- Attempts to adapt current systems may be hampered or hijacked by special interests that are powerful enough to stall or even reverse attempts to effectively address the basic problem.

There is thus some commonality between the literature on solving 'wicked' problems and on the requirements for transformative change. In this final section we comment on ways in which such thinking might affect the policy discussions on the EGD and post-COVID-19 stimulus measures.

4.1 The COVID-19 pandemic and transformative change

While the debate on transformative change preceded the COVID-19 pandemic, several authors have pointed to 'business-as-usual' as having contributed to the increased frequency of spill-over of diseases from wildlife to people. Deforestation, uncontrolled expansion of agriculture, intensive farming, mining and infrastructure development, and exploitation of wild species all create increased opportunities for cross-species transmission. In this way (combined with the explosive growth of global air travel), a virus that once circulated harmlessly among bats in Southeast Asia has now infected over 40 million people, and continues unabated.

Gibb *et al.* (2020) found that converting natural ecosystems to agriculture benefits smaller, more adaptable creatures that carry more pathogens that can potentially transmit to humans. Settele *et al.* (2020) argue that future pandemics are likely to happen more frequently, spread more rapidly, have greater economic impact and kill more people, if we do not ensure that actions now being taken do not amplify risks of future outbreaks and crises. They point to criteria that should be central to the multi-trillion-dollar recovery and economic stimulus plans. Among these are that environmental regulations should be strengthened and enforced — the opposite of actions in some countries to weaken such regulations. Stimulus packages should be restricted to incentives for more sustainable and nature-positive activities, which are robust and properly monitored to ensure that they are not diverted from their original objectives. Further, a holistic approach is required that recognises the complex interconnections among the health of people, animals, plants and our shared environment (a 'one health' approach). As advocated by IAP (2020), a green post-COVID-19 recovery must be designed to generate co-benefits for social equity, the environment and human health.

Much has been made of the unprecedented fall in GHG emissions as a result of the rapid reduction in economic activity, particularly in industrial activity and transport. However, even this unsustainable disruption to society has failed to reduce CO_2 emissions to a pathway that is compliant with the Paris Agreement. Moreover, as shown by Forster *et al.* (2020), the small reductions in warming resulting from falls in CO_2 and NO_x emissions are partly offset by reductions in sulfur dioxide that weaken the aerosol cooling effect. As emissions recover, the net effect will be negligible. Only by ensuring that economic recovery packages specifically target low-carbon energy supply and energy efficiency, and do not support fossil-fuel-based industries or investments, can this temporary 'blip' in emissions be consolidated and reduce future warming.

4.2 Insights from the analyses of transformative change for the EU

As described in previous sections, there is much agreement on the need for transformative change, and on the concepts and broad objectives involved. Inevitably, to respond to global threats and challenges, a global approach is required. Yet the global issues discussed here are subject to the 'tragedy of the commons' whereby shared global resources fail to be

[21] Wicked problems are multidimensional challenges that are difficult to resolve owing to incomplete or contradictory information, differing views on the nature of the problem or complex interactions with other issues.

protected by countries acting independently according to their own self-interest. Persuading governments to take a longer-term and global perspective requires leadership and, as pointed out by EEA (2020), there is thus an opportunity for European leadership. For instance, in encouraging the 'North' to prioritise in development projects in the 'South', green investments such as renewable energy, material efficiency, regenerative agriculture and afforestation.

With regard to the EU's European Green Deal and post-COVID-19 responses, many stakeholder inputs have emphasised that stimulus measures should not support returning to 'business-as-usual'. This philosophy is found in many national recovery plans and in the OECD (2020) recommendations to 'build back better', whereby policies trigger investment and behavioural changes that focus on well-being and inclusiveness, and *inter alia* meet emission reduction goals, reverse biodiversity loss and promote circularity in economies. EASAC (2020) has also emphasised the wide range of technological solutions available to address the challenges in the fields of

- decarbonisation together with economic recovery;
- recognising the value of ecosystem services;
- policies for economic recovery that will accelerate the energy transition;
- protecting and improving human and planetary health.

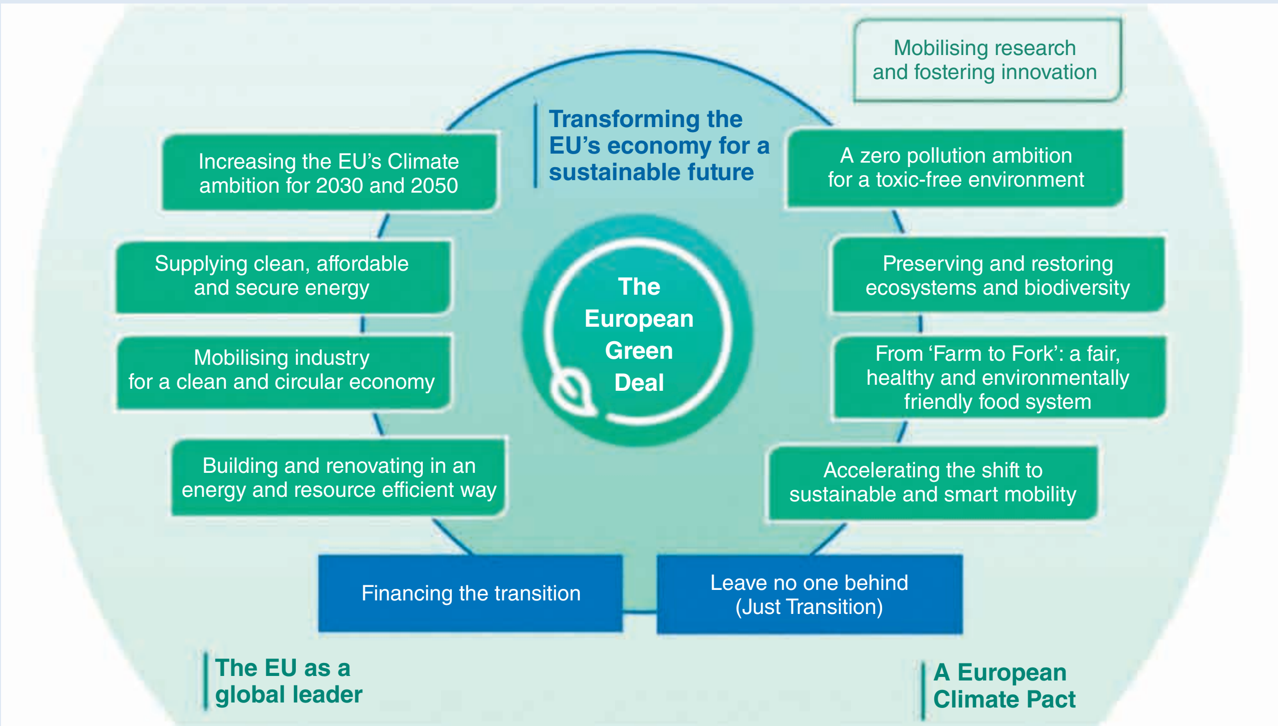
Current European Green Deal and biodiversity policies are summarised in Box 4. The visions and action

Box 4 The European Green Deal (EC, 2019) and Biodiversity Strategy (EC, 2020a)

The EGD notes that '*The atmosphere is warming and the climate is changing with each passing year. One million of the eight million species on the planet are at risk of being lost. Forests and oceans are being polluted and destroyed*'. The European Green Deal is a response to these challenges — a new growth strategy that aims to **transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy** where there are **no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use**. It also aims to **protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks** and impacts. At the same time, this transition must be **just and inclusive**.

The framework and component parts are shown in the box figure below. Key elements are

- European Climate Law to ensure a climate neutral European Union by 2050, and public consultation on a European Climate Pact;
- a European industrial strategy and circular economy action plan;
- farm to fork strategy to make food systems more sustainable;
- EU Biodiversity strategy for 2030.



Box 4 Figure The European Green Deal (EC, 2019).

The EGD recognises the need for transformative change encompassing '*a rethink of policies for clean energy supply across the economy, industry, production and consumption, large-scale infrastructure, transport, food and agriculture, construction, taxation and social benefits*'. To achieve these aims, it is essential to increase the value given to protecting and restoring natural ecosystems, to the sustainable use of resources and to improving human health. In addition, the risk must be avoided of carbon leakage through production being transferred to other countries with lower ambitions for emission reduction, or because EU products are replaced by more carbon-intensive imports. The EU must take a leadership role in persuading other countries to share these aspirations and polices but must be prepared to apply necessary countermeasures if necessary (e.g. border tax adjustments, trade tariffs or trade bans).

The 2030 Biodiversity Strategy

Associated with the EGD is the new 2030 Biodiversity Strategy (EC, 2020a) which presents a long-term plan for protecting nature and reversing the degradation of ecosystems. It is a key pillar of the EGD and of EU leadership on international action for global public goods and SDGs.

Key goals include the following.

- Transforming at least 30% of Europe's lands and seas into effectively managed protected areas.
- Restoring degraded ecosystems across the EU. This will include restoring the most carbon-rich ones; rivers; reversing the decline in farmland birds and insects; reducing the overall use of and risk from chemical pesticides; enhancing the uptake of agro-ecological practices; reducing the losses of nutrients from fertilisers; planting at least 3 billion trees; protecting remaining primary and old-growth forests; and other measures.
- Enabling **transformational change** to improve biodiversity governance, establish a Biodiversity Knowledge Centre and a Biodiversity Partnership to support better implementation of biodiversity research and innovation in Europe. Also, the strategy will aim to stimulate tax systems and pricing to better reflect real environmental costs (including biodiversity loss), and integration of biodiversity into public and business decision-making.

The strategy points to the synergies with climate change and COVID-19 recovery measures and aims to allocate at least €20 billion per year for spending on nature. The Commission will also seek to influence the CBD by advocating global 2030 targets in line with EU commitments, as well as better means of implementation, monitoring and review.

blueprints summarised in section 3 share similar technological objectives to those of the EGD, but also point to a need to tackle the underlying system drivers and governance weaknesses that hinder the changes in priorities and actions required. Section 2 also included several issues or weaknesses that contribute to unsustainable development such as continued increases in global population; short-term thinking of economic assessments and political decision-making in democracies; failure to properly quantify the value of the natural capital being lost or the scale of the existential threat to society of current trends; dominance of GDP in economic and political decisions; as well as the protection by special interests of the system from which they benefit.

From the analyses in previous sections, implementing the EGD and stimulus measures could benefit from further attention to the following aspects.

4.2.1 Replacing GDP with indicators of human well-being

The search for indicators to replace GDP was summarised in section 2.5.1. In view of the extensive work already conducted, the lack of a swift conclusion on the well-being indicators to be used (e.g. ISEW, GPI or the Inclusive Wealth Index) may reflect political and institutional resistance. The EU programme of 'Beyond GDP' continues, and a recent Council statement (EC, 2019a) asserted the importance of '*the task of improving and developing, in cooperation with the EU institutions, reliable and internationally comparable indicators for measuring and monitoring people's wellbeing*'. The introduction of indicators of well-being alongside GDP is one pre-condition for transformative change, and a priority is to progressively replace GDP's role in economic and political decision-making. Human well-being need not depend on intensive resource use. There are large variations in the amounts of biophysical resources consumed to achieve common social objectives, and several countries have stayed within biophysical boundaries while achieving their social goals. Such studies (see, for example, Van den Bergh 2011; Van den Bergh and Kalli, 2012; O'Neill *et al.*, 2018) provide best-case examples to encourage dialogue on how to advance human development within the sustainability limits of nature.

4.2.2 Overcoming the excessive influence of special interests

The analyses in section 3 identified major obstacles to change as including vested interests that are benefiting in the short term from unsustainable practices. These include owners of fossil fuels who stand to suffer large capital losses from the move to zero-carbon energy, and the beneficiaries of unsustainable land and ocean practices; for instance, cattle ranchers engaged in deforestation and land clearing, and fishing fleets engaged in overfishing. Current subsidies to sectors such as fossil fuels, extractive industries and fishing are huge and strongly protected. For instance, the global fossil-fuel industry gained US$4.7 trillion in 2015 from

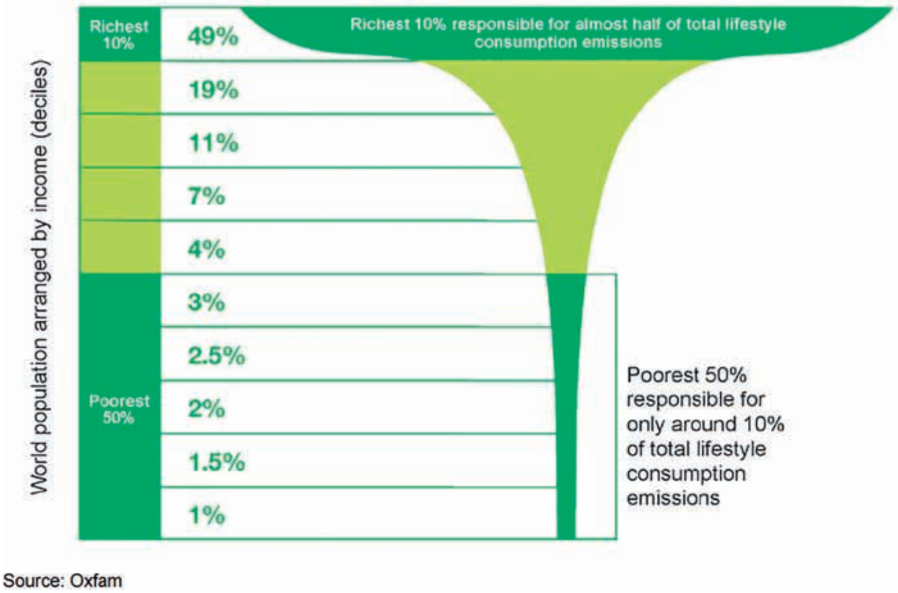


Figure 11 Percentage of CO_2 emissions by income in the global population. Source: https://sminpowergroup.com/percentage-of-co2-emissions-by-world-population-and-income/.

the taxpayer (Naidoo and Fisher, 2020). Despite all the rhetoric in support of a green recovery targeted at climate change and biodiversity, initial actions show the resistance to change – G20 actions show over US$150 billion to support fossil fuels – almost double the US$88 billion allocated to supporting clean energy (https://www.energypolicytracker.org/).

Opposition is also anticipated from elite groups more generally. Major wealth owners are typically resistant to the taxation needed to fund public services and public investments. The effect of the huge disparities in consumption between individuals was mentioned earlier in the context of population (section 2.5.1) but the importance of addressing this issue can be seen in Figure 11 where the dominance of higher-income groups on CO_2 emissions is illustrated.

Opposition results from the substantial trade-offs associated with transforming society toward more sustainable pathways — trade-offs that can have substantial impacts on individual stakeholders. This is a field where social sciences, not the least economics, can help highlight the trade-offs, design policy instruments that minimize their burden, and help overcome behavioural biases or cognitive limitations that people might have that prevent them addressing the fundamental problems.

4.2.3 Public awareness

Broad public support is essential to provide the political motivation to tackle long-term environmental issues that require policies across decades. Governments and professional bodies can provide information (including through traditional media and science communication programmes). However, the common sources of information in the past (print and television media) that led to a relative convergence of societies around basic norms and values are being replaced by social media and its highly funded 'fake news', propaganda and misinformation.

Public engagement to increase awareness and engage in the policy process can be a role for the scientific community which can develop better tools and methods for multi-stakeholder engagement. Social and behavioural scientists can assist in co-designs of policies with sustainable long-term pathways, while improving public acceptance and implementation. Current tools include citizen panels, focus groups, online consultations/surveys, expert panels or meeting(s) with interest groups (consumers' associations, trade unions, business associations, etc.). Participatory and deliberative democracy that increases citizen engagement has been shown to increase support for policy (see, for example, Mische, 2014; Hajer and Pelzer, 2018; Nakagawa *et al.*, 2019). Recently, citizen assemblies have been established to explore climate change policies that are both effective and acceptable to the majority of the public (Box 5).

Such methods can interact through the EU's Multi-Stakeholder Platform set up in 2016 to inform the implementation of the SDGs. Research models such as those trialled by Rooney-Varga *et al.* (2020) may be of interest: their Climate Action Simulation increased

Box 5 Citizen assemblies on climate change

Public engagement in policy development goes back to the start of technology assessment in the 1970s (e.g. the Danish Parliament's consensus conferences (Vig and Paschen, 1999)) and similar approaches have recently been deployed through two citizen's assemblies addressing the issue of climate.

In France, the assembly's 150 members, drawn from a cross-section of society were tasked to come up with measures to reduce the country's emissions at least 40% by 2030 from 1990 levels '*in a spirit of social justice*'. Fifty proposals have been recommended to the French government to influence Covid-19 recovery priorities. (https://propositions.conventioncitoyennepourleclimat.fr/pdf/CCC-propositions-synthese.pdf).

In the UK, the parliament (through six of its select committees) supported a Climate Assembly to advise on reaching the UK's net zero target of 2050. The assembly's 108 members represented a cross-section of gender, ethnicity, educational level, where they lived and different levels of concern about climate change. The assembly recommended general principles that should guide policy and specific recommendations on targets for emissions reduction in the fields of: travel (land and air), in the home, diet and how we use the land, what we buy, electricity sources, GHG removals and role of COVID-19 recovery. The UK Parliament will use the report to support its work on scrutinising the Government's climate change policy and progress on the target (https://www.climateassembly.uk/report/).

participants' knowledge about the scale of actions needed to address climate change, and increased their personal and emotional engagement with climate change. Such efforts, however, may have a limited effect while the major social media platforms continue to offer little in the way of quality filters on the false and misleading material undermining rationale debate. This remains a major technical and political challenge.

4.2.4 Industry engagement

A critical challenge is to convince industries and investors that meeting Paris Agreement targets, the 2030 SDGs and reversing biodiversity loss is a better business opportunity than trying to protect the old 'business-as-usual' fossil-fuel-based economy. The penalty of being wrong is much higher if climate change is not addressed and the damage turns out to be large, compared to mitigating climate change when the damage turns out to be small (Hassler *et al.*, 2018). Avoiding such high risks is possible by the measures advocated by the WEF in section 3, while Box 6 presents conclusions of the Business and Sustainable Development Commission (BSDC, 2017). There is a role here for governments to adapt the rules on corporate governance to encourage businesses to pursue social and environmental sustainability as much as they pursue market share and shareholder value. The SDGs can provide an important new lens through which business can explore new opportunities, more effectively manage its risks and secure an enduring license to operate. Science may also be able to work with business to understand their role in harming the biosphere and find constructive ways towards more sustainable futures (e.g. Folke *et al.*, 2019).

However, as we have seen in previous sections, changes in economic criteria such as cost–benefit analysis and priorities in the financial sector are changing only slowly. The ambitious goals in decarbonisation, reversing biodiversity loss and other fundamental conditions for sustainable development cannot overlook these structural barriers, and warrant increased attention and action alongside the technical objectives of the EGD. In this context, the work of the WEF may offer an opportunity to develop international sectoral platforms to develop consensus across the public, industry and policy-makers on transitions to a sustainable economy.

4.2.5 International actions

The EGD fully recognises the importance of the international dimensions of transformative change; these include the ultimate need to plan for a situation where the actions of other countries fail to match the climate and biodiversity measures within the Union, and thus distort competition and create barriers to trade. Minimising such conflicts requires that the international organisations involved (particularly the World Trade Organization, UNFCCC and CBD) be encouraged to align international rules and procedures as far as possible to those of the EU. This will require an active leadership role by the EU and Member States in these fora.

The Commission has laid out specific measures in the new biodiversity strategy (EC, 2020a) to strengthen international actions in reversing biodiversity loss via the CBD (Box 4). Such measures need (IPBES, 2019) to enhance international cooperation on conservation, ecological restoration and sustainable use; to align local, national and international sustainability efforts; and to mainstream biodiversity and sustainability considerations into all extractive and productive sectors. Sustainability planning at all levels needs to align development policies into wider biodiversity and nature objectives, and at the minimum ensure that individual developments should result in no net loss of biodiversity.

Box 6 Business opportunities in meeting the SDGs

A 2017 review by the Business and Sustainable Development Commission (BSDC, 2017) encourages businesses to embrace an '*economic model which is not only low-carbon and environmentally sustainable, but also turns poverty, inequality and lack of financial access into new market opportunities for smart, progressive, profit-oriented companies*'.

Businesses, in principle, should share the goals of a world that is sustainable; socially fair; environmentally secure; economically prosperous; inclusive; and more predictable. However, many see these as the job of governments, not the task of business. The key is thus to engage business and incentivise it to see achieving the SDGs as a growth strategy for individual businesses. Overall, the BSDC points to at least US$12 trillion of market value which could be unlocked per year if the SDGs are realised by 2030, creating more than 380 million jobs in the process.

Major markets are food and agriculture, cities, energy and materials, and health and well-being, representing around 60% of the real economy. The main sectors evaluated are in the box figure below.

	Food and Agriculture	Cities	Energy and Materials	Health and Well-Being
1	Reducing food waste in value chain	Affordable housing	Circular models - automotive	Risk pooling
2	Forest ecosystem services	Energy efficiency - buildings	Expansion of renewables	Remote patient monitoring
3	Low-income food markets	Electric and hybrid vehicles	Circular models - appliances	Telehealth
4	Reducing consumer food waste	Public transport in urban areas	Circular models - electronics	Advanced genomics
5	Product reformulation	Car sharing	Energy efficiency - non-energy intensive industries	Activity services
6	Technology in large-scale farms	Road safety equipment	Energy storage systems	Detection of counterfeit drugs
7	Dietary switch	Autonomous vehicles	Resource recovery	Tobacco control
8	Sustainable aquaculture	ICE vehicle fuel efficiency	End-use steel efficiency	Weight management programs
9	Technology in smallholder farms	Building resilient cities	Energy efficiency - energy intensive industries	Better disease management
10	Micro-irrigation	Municipal water leakage	Carbon capture and storage	Electronic medical records
11	Restoring degraded land	Cultural tourism	Energy access	Better maternal and child health
12	Reducing packaging waste	Smart metering	Green chemicals	Healthcare training
13	Cattle intensification	Water and sanitation infrastructure	Additive manufacturing	Low-cost surgery
14	Urban agriculture	Office sharing	Local content in extractives	
15		Timber buildings	Shared infrastructure	
16		Durable and modular buildings	Mine rehabilitation	
17			Grid interconnection	

Box 6 Figure Biggest market opportunities related to delivering the global SDGs.

5 A final word

This overview of the mismatch between the current rate of change and the size of the challenge aims to help non-expert readers understand the reasons for calls for transformative change. We have provided an initial analysis of areas where the transformative vision requires approaches different to, or in addition to, the comprehensive policies already under development within the EGD and post-COVID-19 stimuli. The conclusion of this initial analysis is that there are fundamental barriers that will make it difficult to achieve current objectives; objectives that are themselves insufficient to address the planetary level challenges that threaten society's future. This thus encourages policy-makers to consider the broader structural issues identified here in the fields of economics, public awareness and resistance to change in parallel with introducing more technical and regulatory measures.

The aim would be to create frameworks where changes already underway at the margins or as niches can accelerate transition to a sustainable future. Relevant here (in addition to the already-mentioned field of complexity science) is the work on 'transition science' (Kohler *et al.*, 2019) which has exploded in the past 10 years, giving rise to several analytical frameworks (e.g. multi-level perspective, technological innovation system, strategic niche management, transition management) and it may be timely for such research to engage more directly with the policy environment. Transitions are inherently political processes in resolving conflict between winners and losers in the changes required. As noted by Kohler *et al.*, incumbent industries are threatened and often exercise power to protect their vested interests and resist transformative innovation. At the same time, new entrants or actors in favour of alternative socio-technical configurations will require public support. There may be a need for a particular emphasis on urban transformations owing to their dominant role as living space for a majority of the global population and as a source of emissions and resource demand (Elmqvist *et al.*, 2019).

Initial initiatives to 'restart' economies after COVID-19 already have started to go back to old paradigms of stimuli (increase consumption, build more roads, etc.) and the more fundamental thinking that has blossomed during the COVID-19 crisis may be short-lived if the inertia from 'business-as-usual' in current stakeholders and politics is not confronted with the reality of the challenges we face.

In conclusion, this Perspective shows that addressing climate change, loss of biodiversity and resource depletion cannot avoid addressing the underlying drivers of unsustainable consumption and production patterns in society's core systems, whether they be electricity, heat, buildings, mobility, agriculture or food. These conclusions challenge the social and political paradigm of at least the past 70 years where leaders have campaigned on the basis of continuing improvement in the traditional economy, with science and technology expected to allow economic growth to be indefinitely sustained. Recognising the realities of future human development within our finite planet will require a paradigm shift[22] in the discourse of democracy's political leaders, to achieve a transformative cultural change in society, and it presents a major challenge to our political systems to support long-term policy-making.

Science (IAP, 2020; Viglione, 2020) can help in several ways identified here, including research and development (e.g. on large-scale CO_2 removal and utilisation), but its impact will be limited in the absence of the political and cultural components of transformational change. As major reforms of our underpinning economic paradigms are involved, politics will have to lead; as stated by Acemoglu and Robinson (2012): '*While economic institutions are critical for determining whether a country is poor or prosperous, it is politics and political institutions that determine what economic institutions a country has.*'. It is therefore hoped that this overview may assist policy-makers in understanding and assessing the broader structural issues identified here in parallel with current policies aimed at more technical and regulatory measures.

[22] As noted in the review by Dasgupta (2020), recognising that '*humanity and our economies are embedded in the biosphere has profound implications*'. If the global economy is seen as embedded in Nature, growth in global output can grow indefinitely only if the efficiency with which we are able to transform the biosphere's goods and services into final products also grows indefinitely.

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Abbreviations

BSDC	Business and Sustainable Development Commission
CBD	Convention on Biological Diversity
CO_2	Carbon dioxide
EASAC	European Academies' Science Advisory Council
EEA	European Environment Agency
EGD	European Green Deal
EU	European Union
G20	Group of Twenty countries
GDP	Gross domestic product
GHG	Greenhouse gas
GISS	Goddard Institute for Space Studies
IAM	Integrated assessment model
IAP	InterAcademy Partnership
IEA	International Energy Agency
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRP	International Resource Panel
MEA	Millennium ecosystem assessment
NASA	National Aeronautics and Space Administration
OECD	Organisation for Economic Co-operation and Development
PETM	Palaeocene–Eocene thermal maximum
p.p.m.	Parts per million
POP	Persistent organic pollutant
SDG	Sustainable Development Goal
TWI2050	The World In 2050
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WEF	World Economic Forum

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