THE IMPACT OF CLIMATE CHANGE ON COST OF LIVING IN THE UK

SCIENTISTS
WARNING
EUROPE

Author: Dr Paul Behrens

Citation and acknowledgements: Behrens, P. The Impact of Climate Change on UK Cost of Living: a Report for Scientists Warning Europe, 2023, https://www.scientistswarningeurope.org.uk/cost-of-living.

This report has been prepared at the request of Scientists Warning Europe. The views and positions expressed in this paper are those of the author and do not necessarily reflect the views of Scientists Warning Europe.

About Paul Behrens
Paul Behrens (UK) is an author and Associate Professor at Leiden University. His popular science book, The Best of Times, The Worst of Times: Futures from the Frontiers of Climate Science (Indigo Press, 2020) describes humanity's current trajectory and possible futures in paired chapters of pessimism and hope, on topics including the economy, energy, land and food. He outlines just how much is to be done to achieve a hopeful future, but how this scenario would involve actively building a healthier, happier and more fulfilling world. His research and writing focusses on the areas causing most of the problems: energy, food and economic systems. His research and writing has appeared in scientific journals and media outlets such as the BBC, Thomson Reuters, Politico, Nature Sustainability, Nature Energy, the Proceedings of the National Academy of Sciences, Nature Food and Nature Communications. He is International Champion of the Frontiers Planet Prize.

Executive summary

The impacts of COVID, conflict, and climate change have driven consumer prices higher around the world, increasing the cost of living. As a result, there were an estimated 12,500 protests across 148 countries during 2022. The UK faced regular strikes over pay and working conditions. Climate change impacts will continue to worsen driving climate-related increases in cost-of-living in the UK and internationally. These impacts can be directly experienced by consumers, such as crop failures driving up food prices. They can also be indirect, such as flood-induced infrastructural damage and productivity losses.

> *The magnitude of risks is also increasing faster [in the UK] than earlier assessments predicted. Today's risks are more numerous and more severe than the first CCRA in 2012 predicted for the 2020s*
>
> The Third United Kingdom Climate Change Risk Assessment, 2021

Underestimating climate impacts Globally, Intergovernmental Panel on Climate Change (IPCC) assessments find that climate impacts are coming sooner and harder than previously thought. They also find that the speed of adaptation to climate change is insufficient to cope. Economic and ecological impacts that were thought to begin at 3°C of warming in 2001 are now expected at around 1.5°C (as of 2022, see Figure 1a). Underestimations have been due to deep uncertainty in how Earth's climate system responds to increasing temperatures and issues in economic modelling.

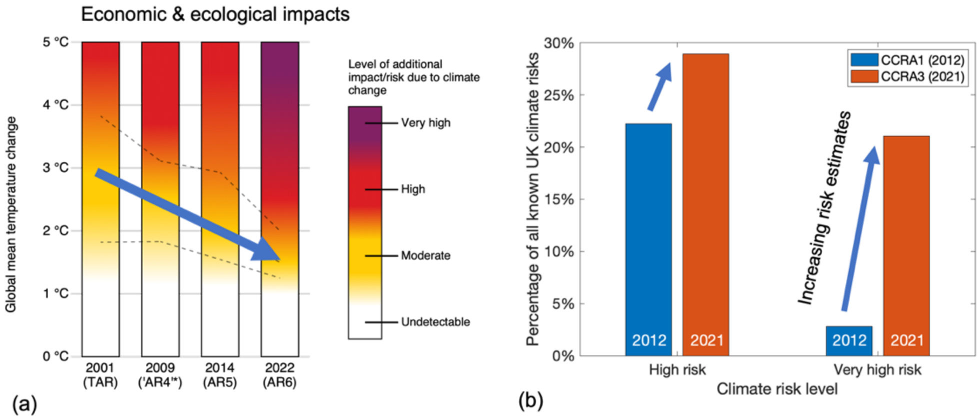

Figure 1 Increasing impacts and risks over time for the world (a) and the UK (b). (a): the climate risk for a level of warming in IPCC assessments over time. There are higher risks at lower temperatures (Behrens, P. & Marbaix P., 2023) (b): the proportion of known climate risks assessed as 'high' or 'very high' in the 2012 and 2021 UK Climate Change Risk Assessments. Very high risks are risks that have over £1 billion of damage per year to the UK economy (Behrens, P., 2023 based on UKCCRA data).

Underestimating the UK's exposure to climate damage Regionally, past assessments found that northern Europe and the UK would experience equivalent climate impacts *later* than the rest of the world, due to the more temperate climate. However, Northern Europe has seen earlier-than-expected impacts from extreme weather events. For example, the UK's Third Climate Change Risk Assessment (UKCCRA3), paint a stark picture for communities across the UK in the short- and medium-term. These impacts will inevitably have a strong bearing on the cost of living across the UK.

In 2021 the UKCCRA3 found that the proportion of high and very high risks for the same level of warming are increasing over time (see Figure 1b). For example, percentage of very high risks equating to economic damages of £1 billion per year by 2050 under a 2°C scenario increased from under 5% in 2012 to over 20% in 2021. There is some evidence that UK climate impacts are still being systemically underestimated. For example, in 2021 the UKCCRA3 found that the median chance of exceeding 40°C by 2040 was 0.02% and 0.05% by 2080 (0.16% in London). Yet by 2022, decades ahead of schedule, multiple regions in the UK – urban and rural – broke the 40°C threshold. While this is only one example, there has been a general systematic underestimation of climate risks both at international and UK levels.

An increasing cost of living drives social instability Conflict in Ukraine, post-COVID supply chain interruptions, and Brexit have also all driven increases in UK cost of living. Climate impacts combine with other geopolitical and national pressures. A recent example is the limited availability of imported fruit and vegetables driven by a 2022-2023 winter drought across southern Europe coinciding with Brexit-related trade difficulties, and farming expenses due to the Ukraine war. The UK is more reliant on international supply chains than similar countries and is particularly exposed to climate damages across international trade partners. International climate impacts are estimated to account for roughly half the UK's economic climate costs. These trends are set to continue in the short term (for the next two decades), but rapid emissions mitigation can have a substantial easing effect over the medium- to long-term (from around 2040 onwards).

Climate change will drive a continually increasing trend via the combination of climate events *and* global shocks. This combination can push communities beyond coping thresholds (see Figure 2 for an indicative trajectory). As the costs of living increases, communities can reach points of critical transition, popularly called "tipping points". Indicators for the onset and unfolding of these transitions are strikes over pay, political unrest, cost of living protests, food riots, and ensuing political destabilisation. Extreme weather events combined with other factors across low- and middle-income nations have already pushed communities across these thresholds in numerous cases such as in Syria. The dynamics of societal instability driven by increasing costs of basic goods have been well-demonstrated across the academic literature.

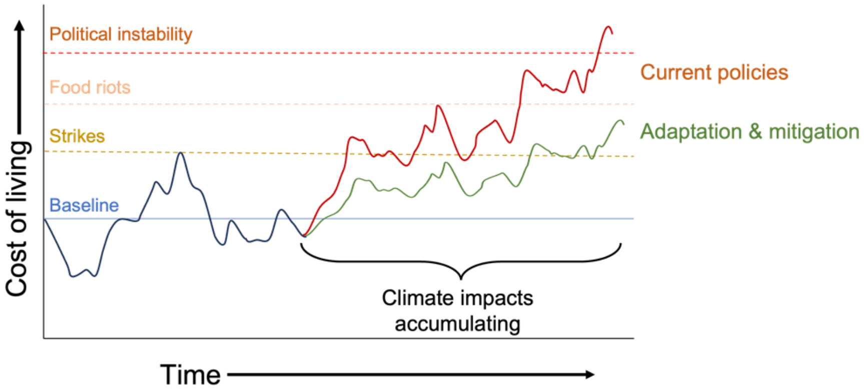

Figure 2 An example of how climate impacts combine with other shocks to increase cost of living in the UK. The baseline shows an average cost without the impact of climate change against two scenarios going forward – current policies and adaptation & mitigation – to indicate the increase in cost of living over time as climate impacts accumulate. As the cost of living increases, the coloured dashed lines show the potential for societal tipping points or volatile transitions, from strikes to political instability. (Behrens, P., 2023)

Increases in cost of living are felt most across the lowest income groups in UK society, just as they are in the lowest income nations of the world. These groups spend a larger percentage of their total income on basic goods such as food – goods that are most exposed to climate risks and price increases. The poorest will continue to experience impacts earlier and more deeply than other income groups. However, higher income groups are already seeing impacts, given the broad scope of climate threats to society's support systems.

Researchers have identified over 400 pathways through which climate change threatens humanity. The scale and range of impacts make cost assessments fraught with uncertainty, and we should be humble about the accuracy of any future cost estimates, let alone how this may impact cost of living. As such, this review surveys the literature on economic costs, accounting for the direction of systemic under- or over-estimations over time, and the broader qualitative picture for climate's impact on sectors comprising cost of living expenditures. Where possible, the review puts these economic costs in terms of the cost of living.

The report finds significant climate impacts on the cost of living across food, energy, health, and built infrastructure. Without substantial mitigation and adaptation, it finds that for:

- **Food:** impacts emerge earlier than previously estimated and the risk of multi-breadbasket failure[1] increases dramatically at 1.5°C. The UK is heavily exposed to international climate impacts as a significant importer of food. Food prices are likely to stay high, or even increase, even in the short-term. Extreme weather is already having a deep impact on UK farming and tipping elements in the climate system could have radical impacts on the potential for future food security.
- **Energy:** impacts will center on: exposure of energy system infrastructure to flooding; geopolitical tensions in access to energy supplies; and climate impacts on the availability of renewable energy (e.g. changes to precipitation for hydropower and wind availability for wind power).
- **Health:** major impacts on cost of living are likely to be direct in the form of welfare losses due to extreme weather (flooding, heatwaves, etc.), and indirect via tax rises to pay for increasing NHS costs or productivity losses due to disability. The NHS will be exposed to new threats from novel diseases spreading further north as the country warms, from the emergence of zoonotic diseases, and antimicrobial resistance.
- **Infrastructure:** impacts will be largely driven by flooding damage, but heatwaves, subsidence and wind damage will also drive large losses. The largest costs are experienced when critical infrastructure such as electricity networks are damaged with downstream economic costs when public services are interrupted.

The many benefits of net-zero transitions The report also explores how net-zero transitions in energy and food are often cheaper than business as usual in purely market costs. If non-market costs such as air pollution are included, they can be orders of magnitude cheaper. Transitions will have dramatic impacts on cost of living. For example:

- **A rapid food system transition** has the potential to reduce food costs while improving climate resilience, health outcomes, and saving land. Shifts to healthy diets in the UK could free an area almost the size of Scotland. Farmers could be paid to use land for flood adaptation, carbon sequestration, biodiversity protection, and public access to nature for further benefits.
- **A rapid energy system transition** by 2050 is cheaper than a slower transition by 2070 when accounting for economic costs alone across the world. When including welfare costs, UK savings would be in the order of billions of pounds. There is an academic consensus that the energy transition offers the greatest economic opportunity this century, would create jobs, and would insulate the public from fluctuations in energy prices, lowering inflation and limiting increases in the costs of living. Estimates suggest that the average household will save at least £400-6,000 cumulatively by 2050 through a net-zero transition. GDP is estimated to be around 2-3% higher by 2050 with a net-zero transition. These estimates are likely to be significantly higher given increases in fossil fuel energy costs.

Net-zero climate mitigation policies often represent no-regret options. They are cheaper in economic, health, environment, and climate adaptation costs. They will limit the increases to cost of living from climate impacts. However, there are social and political challenges in harnessing the technological and behavioural changes that represent the largest opportunities, for example planning requirements for renewables or shifts to a much higher proportion of plants in diets. While there are large-scale benefits to the transition there are incumbent actors within major emitting industries that will lose out.

Accelerating the timeline Given increasing climate impacts and large mitigation opportunities, net-zero could be accelerated to earlier than 2050. Setting an earlier goal for 2040 or 2030 could provide the anticipated benefits of net-zero earlier at low to negative cost. That is, moving faster in energy and food transitions may be better for the country, both economically and environmentally.

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[1] often defined as a 10% reduction across major world grain producing regions in the same year

Research has shown that a faster energy transition is cheaper on purely economic costs alone, but this has only been established by academic modelling up to 2050 when compared to 2070. However, in 2020 the UK's Climate Change Committee estimated that the costs and savings from the net-zero transition by 2050 are expected to cancel out around 2043-2044 (see Figure 3). This assessment was based on information before the price increases resulting from the Russia-Ukraine war. For reference, some estimates suggest higher wholesale gas prices over the year after the Russian Invasion of Ukraine cost the UK an additional £50-60 billion. This finding is based on a middle-of-the-road pathway with central estimates for behaviour and technological change. Increasing climate impacts may feedback and increase both of these factors, lowering costs.

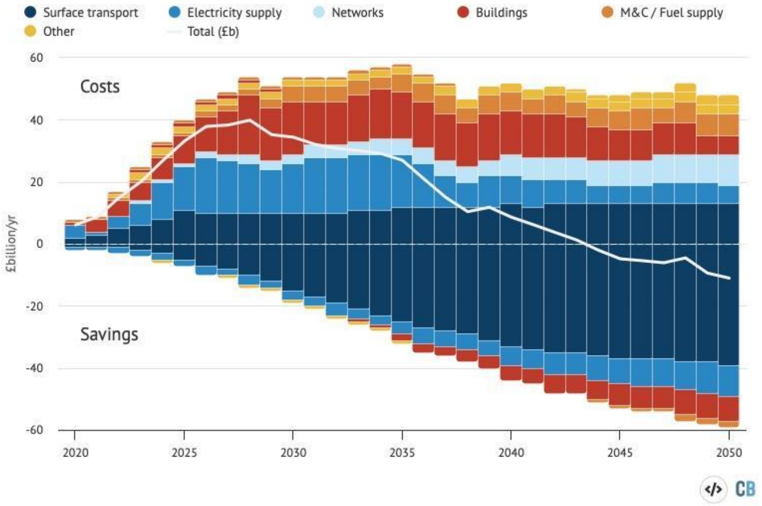

Figure 3 Costs and savings of a net-zero transition by 2050 as calculated by the Climate Change Committee in the 6th Carbon Budget Advice. These values are prior to Russia's invasion of Ukraine and are calculated on a central, 'balanced' pathway. Data from (CCC 2020b). Visualization by Carbon Brief (Gabbatiss 2023)

Whether a transition by these dates would be cheaper substantially depends on the cost of capital and labour. Since many energy transition technologies are capital intensive and amortize over the lifetime of each project, the economic costs of a faster net-zero target by 2030 or 2040 may depend greatly on the cost of capital. Further, an earlier transition will require a faster training of net-zero workers which may present labour constraints and increased labour costs. Further economic modelling is necessary to evaluate these costs and benefits however current economic models may struggle to capture these rapid dynamics.

The case for no-regret food-system transition has not yet been established in the scientific literature. However, it is extremely likely that food transitions in diets, waste, and production will provide greater resiliency, improved health, lower environmental damage, and greater food security resulting in lower costs. This has to be driven by a reform of agricultural incentives and a shift in diets with concomitant shifts in production away from animal agriculture and towards fruits and vegetables.

The net-zero transition has been identified as the economic opportunity of the 21st century by numerous agencies and reviews. It has been estimated that the market opportunity of net-zero to British businesses is worth £1 trillion 2030, growing larger past 2030. Government estimates place the number of jobs required in the transition at 480,000 (reviews place the estimate somewhere between 135,000 and 725,000 net new jobs). An estimated 250,000 new jobs have already been created in the transition so far. The race for net-zero is speeding up internationally, with the US, EU, and China all releasing major investment packages. However, there are no signs of any similarly ambitious package being developed in the UK.

Adaptation to climate change has very high economic returns and, importantly, some mitigation strategies could represent significant adaptation opportunities themselves. These actions may lower cost of living in the short term, for example sparing agricultural land and returning it to nature could lower the impact of flooding. However, the need for adaptation in the UK is also increasing over time, with 56% of the risks and opportunities assessed in the CCRA3 given the highest urgency score, compared to 36% in the previous assessments. A recent assessment suggests the UK is 'strikingly unprepared' for climate impacts and has lost a decade in preparing.

Given the acceleration of climate impacts, the increasing public salience of the issue, the potential for catastrophic climate tipping elements, the potential for geopolitical instability, and climate change's influence on other threats such as biodiversity loss, it is almost certain that moving faster towards an earlier net-zero target will be economically beneficial in both market and non-market costs. This, in turn, will have dramatic implications for the cost of living and the resilience of communities across the UK.

Recommendations Despite the demonstrated benefits of a faster energy transition, the UK is falling behind on the required policies and emission reductions to reach net-zero by 2050. Additionally, it is relying on technologies – such as Bioenergy Carbon Capture and Storage and hydrogen heating systems – that will cost more, that will not deliver the co-benefits of energy and food transitions, and that threaten to increase the cost of living, rather than reduce it. Fortunately, there have been many landmark reports that offer evidence-based guidance for transitioning energy and food systems. The below recommendations for tackling cost-of-living (resulting from climate impacts) overlap with the policy recommendations from various national reviews summarised throughout this report. Also included, is a call to conduct further work to account for the distributional impacts of the net-zero transition, and the development of new models that can investigate the impacts of an earlier net-zero target of 2030 or 2040:

1. Adoption the 300 recommendations of the 2023 Climate Change Committee Progress Report to Parliament.

2. Adoption of the 14 recommendations of the National Food Strategy, ranging from subsidy reform to help farmers transition to more sustainable land use, to improving access to fruit and vegetables for low-income families.

3. Adoption of the UK Climate Change Committee's recommendations for a step change in the National Adaptation Programme to both increase ambition and to ensure delivery of adaptation measures. Adoption of the CCC's 94 2023 climate change adaptation recommendations.

4. Campaign for a national, government-led program for mapping distributional climate impacts on lower income communities and the development of pre-emptive policies for easing the burdens of increasing cost of living.

5. Further modelling to assess benefits of an earlier transition, by 2040 and by 2030. Given the large-scale investment and labour changes that would be needed, this may require the development of new classes of models that account for larger scale changes to the economic system.

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1 Introduction

1.1 Overview of the latest climate science

Underestimating climate change While scientific assessments of average global temperature over time have been excellent (Supran, Rahmstorf, and Oreskes 2023; Hausfather et al. 2020), there has been a systemic underestimation of the speed at which environmental systems can change (Armstrong McKay et al. 2022; Zommers et al. 2020). Although recent reports have seen less underestimation over time, underestimations remain between the Intergovernmental Panel on Climate Change's (IPCC) 5th and 6th Assessment Reports in 2016 and 2022 (see Figure 4). The implications of these large-scale, updated assessments will flow down to the cost of living for communities globally.

The IPCC assesses the risks of several "reasons for concern". Of the five overall reasons for concern, two have seen significant underestimations over time: *aggregate impacts* (total economic and ecological impacts), and *large-scale discontinuities* (abrupt transitions of environmental systems such as rapid Greenland ice loss). Risks and impacts that were thought to happen at 3.8°C in 2001, reduced to around 2°C by 2022 (see panel 4 in Figure 4). Moderate risks now begin around 1°C and, as of 2022, global average temperature change is between 1.2 to 1.3°C. An El Niño in 2023-2024 threatens temperatures temporarily above 1.5°C with current policies pushing temperatures to around 2.7°C by 2100 (CAT 2023). Across multiple reasons for concern there has been a systemic underestimation of impacts over time and a very large increase in risks above 2°C of total global warming (see the 'Very High' purple indication in Figure 4).

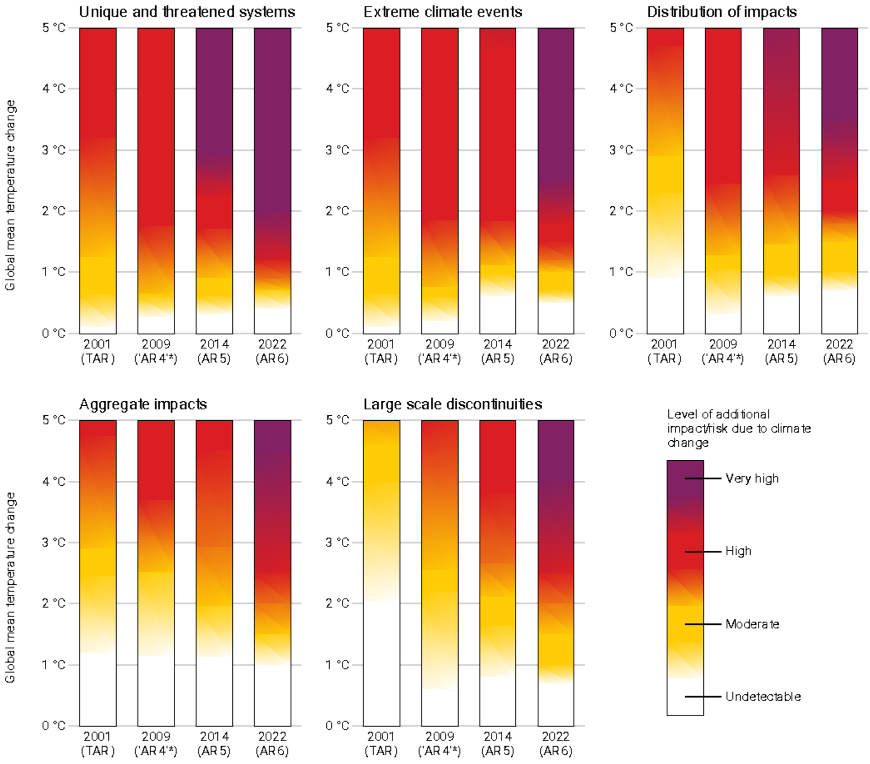

*Figure 4 Each vertical strip or "burning ember" shows the impacts due to climate change for a specific set of risks for a global mean temperature change. Each panel shows the progression in risk assessment over time in each of the IPCC assessment reports, starting with the Third Assessment Report (TAR) in 2001. Dotted lines show the change in assessed temperature required for a climate risk level (Behrens, P. & Marbaix, P 2023). *AR4 burning embers were created separately to the IPCC process by authors involved in the report.*

These underestimations are a consequence of modelling complex outcomes across many scientific disciplines. For example, increasing wildfires across boreal forests in regions such as Russia and Canada can drive further emissions, turning these forests from carbon sinks (that draw carbon out of the atmosphere) to carbon sources (Walker et al. 2014). The rate at which pests such as pine bark beetles could spread north with warming temperatures – providing more fuel for fires – are largely unaccounted for in models (Kurz et al. 2008). At the same time lightning strikes – the ignition source of fires – are increasing due to meteorological conditions (Veraverbeke et al. 2017). Interactions between meteorology, climatology, biology, and ecology make estimating the development of complex systems fraught with uncertainty. On top of this the rate of change in emissions mean we are in an unprecedented situation in which we do not have good data with which to calibrate models.

Overestimating climate resilience The risk and resulting impacts from climate change result from an intersection of hazards (dangers that communities are exposed to), exposure (those people in a hazard area), and vulnerability (the many factors of a community resulting in different vulnerability to the same event) (see Figure 5). Climate change influences the scale of the hazards faced and the number of people exposed. In some cases, climate change can also impact vulnerability, for example drier conditions driving subsidence that damages infrastructure, which can then result in higher vulnerability during flood events.

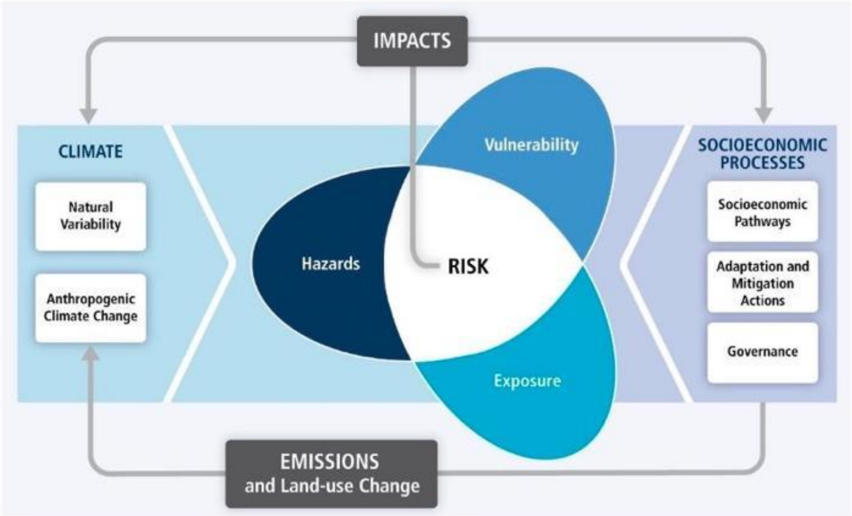

Figure 5 Core concepts of IPCC risk and impact assessment showing feedbacks between concepts. (IPCC 2014)

At the same time as showing a broad underestimation in the scale and range of hazards, IPCC reports have also shown that larger adaptations are needed, resulting in higher economic and social costs. The IPCC states that “Evidence of observed impacts, projected risks […] demonstrate that worldwide climate resilient development action is more urgent than previously assessed” (IPCC 2022). The faster pace in climatic change and the necessity for deeper adaptation has serious implications for resiliency and economic costs, even in the short- to medium-term (defined here as the period between 2025 and 2050). Absent significant policy intervention to mitigate these costs they will become ever clearer in daily life as a continual increase in the cost of living as climate damages increase, especially for those least well off.

Underestimating economic costs There has been a similar underestimation of the overall costs of climate change over time (Rising, Taylor, et al. 2022; P. Wang et al. 2019). The reasons for these underestimations derive not only from systemic underestimations in environmental system change but also due to the economic approximations made for assessing climate damage. One measure of climate cost is the social cost of carbon (SCC) which attempts to produce a cost per ton of carbon emitted. That is, the value of a ton of carbon emission avoided from climate damages. Evidence suggests that the SCC for the US is three times larger than current government estimates at $186 per tCO_2 ($44-413 per tCO2 at a 5-95% range for USD 2020) (Rennert et al. 2022). Yet, even these estimates are fraught with uncertainty (van den Bergh and Botzen 2014). The SSC has also increased significantly over time and the trend is continuing to higher values as we move into the century (Tol 2023). The current carbon prices set by different countries around the world are almost all below even the lower estimates of SCC. Further, previous assessments have used discounting to reduce the value of avoiding future climate change impacts and present-day action, which has added to the systemic underestimation of impacts (Stern 2016).

These analyses largely omit the potential for economic impacts due to climate tipping elements. Climate tipping elements are the potential for irreversible and sometimes very rapid transitions of major environmental systems around the world. Examples include the die off in the Amazon rainforest, Greenland ice sheet loss, and the slowing or cessation of major ocean currents (see Figure 6). These tipping elements, form another significant cost uncertainty. When some aspects of these elements are included, Dietz et al. (2021) find that the SCC increases by 25%, with a 10% chance that the SCC could double. Others find that some large-scale discontinuities can have significant regional economic impacts on the UK. For example, Ritchie et al. (2020) demonstrates that shifts in North Atlantic ocean currents drives significant losses to UK agriculture.

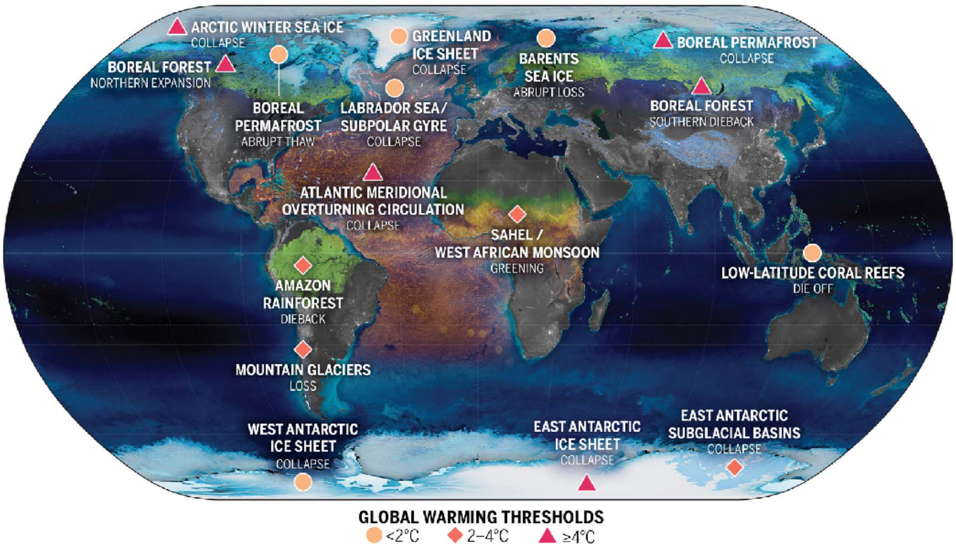

Figure 6 Identified tipping elements around the world and thresholds at which these elements are threatened by destabilstion. Key tipping points for the UK include the Atlantic Meridonal Overturning Circulation (AMOC), and the Labrador Sea/Subpolar Gyre. It is important to note that these thresholds are uncertain. Even if the planet stays below these temperature thresholds these systems can still accelerate, impacting communities before the elements themselves tip. For example, a slowing in the AMOC can impact UK agriculture even if it does not formally collapse.

The size of estimated economic damage is highly sensitive to how climate change impacts productivity over time. That is, whether climate change can impact long-term economic growth. Imagine a year where crop yields are halved due to flooding compared to the flooding and destruction of transport infrastructure. A single year's crop loss may not impact longer-term agricultural prospects. However, infrastructure can take many years, if not decades to rebuild. Destruction of infrastructure has the possibility of reducing long-term economic productivity and slowing growth. The distinction between the two modelling approaches is shown in Figure 7. Models that include these persistent effects generally find economic impacts 10-100 times higher than those that do not (Newell, Prest, and Sexton 2021). Work that looks at the sensitivities of these models suggest persistent economic damage from climate change is the most important factor underlying assessed costs (Kikstra et al. 2021a).

These persistent effects are difficult to observe and model but research has detected them in the US (Colacito, Hoffmann, and Phan 2016; Deryugina and Hsiang 2017). Recent research has detected evidence of persistent effects across many countries and datasets, and some real-world evidence that this can impact long-term economic growth (Bastien-Olvera, Granella, and Moore 2022). For a sense of scale, one study that partially accounted for persistent economic damages globally found a social cost of carbon of between \$2500 to \$7500 per tonne if 10% to 20% of market damage is persistent[2] (in the absence of adaptation)(Kikstra et al. 2021b). For reference, a recent review of estimates worldwide suggest a cost of \$40 to \$525 per tonne depending on the discounting used (Tol 2023). More work needs to be done, but since most economic estimates do not include these persistent effects, tipping points, or multiple damage pathways, published costs are generally significant underestimations.

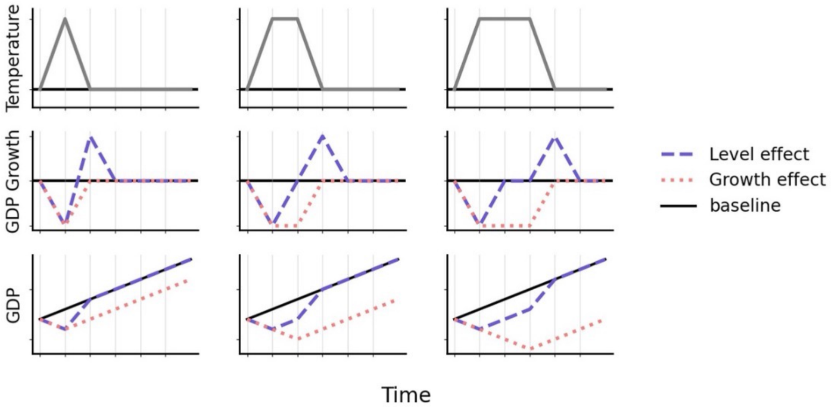

Figure 7 A generalized overview of the two different types of models for economic impact. The level effect assumes that economies 'bounce back' after climate shocks, the growth effect assumes persistent impacts on growth. The top three figures show an increasing length of climate disruption over time. The middle three figures show the impact on GDP growth over time for the level and the growth effect, and the bottom three figures show the overall impact on aggregate GDP over time. Figure from Bastien-Olvera, Granella, and Moore (2022)

Overestimating peak anthropogenic emissions The above trends are concerning but research shows that even the slow and insufficient mitigation actions undertaken by governments has made an impact on overall emissions compared to no actions. Work shows that the estimated emission trajectories this century avoid the very worst scenario used in IPCC reports that assumed even larger use of coal (so-called RCP8.5) (Hausfather and Peters 2020). Work on statistical projections of current progress suggest an earlier and lower peak in emissions that would lead to a total warming in the middle of IPCC scenarios (Yuan et al. 2022). However, these more 'middle-of-the-road' scenarios now have much higher impacts on society due to underestimations in the pace of natural change and the vulnerability of communities.

Underestimating the benefits of mitigation and the desire for action While historical and current efforts are entirely insufficient for maintaining a livable planet, these efforts do show that change is possible. Similarly, there has been a significant estimation of the benefits of emissions mitigation. There have been significant underestimations both in terms of economic and non-economic welfare benefits. Studies have shown that the non-economic welfare benefits of air pollution due to an energy transition are equivalent to net-zero transition costs (Landrigan et al. 2018). Recent work shows that an earlier clean energy transition is very likely cheaper than a delayed transition (Way et al. 2022a) and that energy transition technologies are generally more beneficial for society, government, and resilience due to their modularity and accessibility (Wilson et al. 2020). This will be explored later for the UK context.

There is also evidence that we underestimate the public support for climate action. Recent work has shown that the US public underestimates popular climate policy support (Sparkman, Geiger, and Weber 2022). Figure 8 shows the perceived prevalence of support for major climate policies from 6000 respondents (grey shaded area) while the red vertical line shows actual support levels. The study shows a significant false social reality where each person thinks that the public is more resistant to change than they are. While there is no similar quantitative assessment in the UK, the UK's Citizens Climate Assembly showed significant support for much more ambitious policies (frequent flyer levies, banning SUVs etc.)(Harrabin 2020)

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[2] This is potentially an underestimate. The average value reported includes runs where the SCC was 0 (5-25% of runs) because damages became so high that regions dropped to a subsistence level (with capped consumption, so further emissions did not increase the SCC).

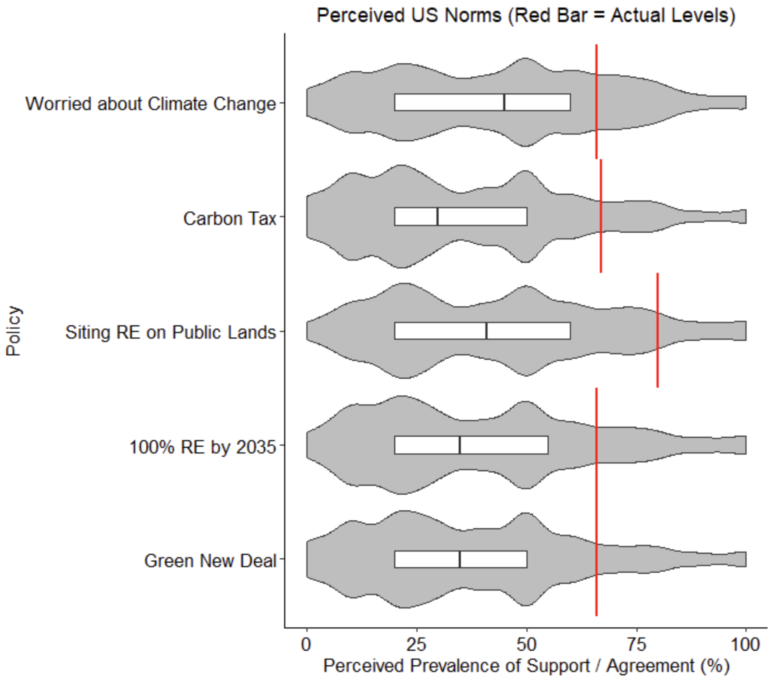

Figure 8.The perceived prevalence of support for different climate policies as reported by 6000 US citizens (grey). The rectangle shows the 25th and 75th percentiles and the vertical black line the median estimate. The red vertical lines show the actual prevalence of support of the respondents (Sparkman, G. et al, 2022).

1.2 UK climate and economic impacts

There are many potential pathways through which climate change can impact communities and cost of living. Mora et al. (2018) found over 400 different combinations of risks through which climate change presents a broad threat to humanity. For the UK specifically, the UK's Third Climate Change Risk Assessment (CCRA3) provided an overall assessment on a narrower set of risks (but not combinations of risk) for 64 different climate change risks and opportunities, from impacts on health to infrastructure damage (Betts and Brown 2021).

The CCRA3's valuation report assessed the costs of these risks into the future, finding that the costs of climate change to the UK economy are already high and increasing (Crown 2022). The valuation report found 8 risks that could see damages of over £1 billion per year at under 2°C of warming (that is, by 2050 or earlier)[3]. These include risks to infrastructure networks from cascading failures, risks to health, and wellbeing from high temperatures, risks from flooding, risks to the finance sector, and risks to investments and insurance (see Appendix for all risks).

As with the global picture, there has been an underestimation of the economic risk from climate change over time. The risks in the 'very high' damage category have risen from 3 to 8 since the CCRA1 in 2012 for the same level of warming by 2050 (see Figure 9). The number of 'Very High' risks assessed in CCRA3 rises to 15-20 by 2080 for a scenario of 4 °C of warming (Watkiss, Cimato, and Hunt 2021). Due to the use of different risk categories in CCRA1 and CCRA3 it is not possible to compare the same risks directly, but we can compare the proportion of risks falling within each risk level. The risk profile increases over time, with the proportion of 'Low' and 'Medium' risks decreasing, and 'High' and 'Very high' risks increasing. This may be an underestimate as there is low confidence in some categories which could not be assessed, such as risks to water quality, biodiversity risks, risks to social care, and more.

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[3] There were several risks that could not be assessed for economic impacts due to deep uncertainties.

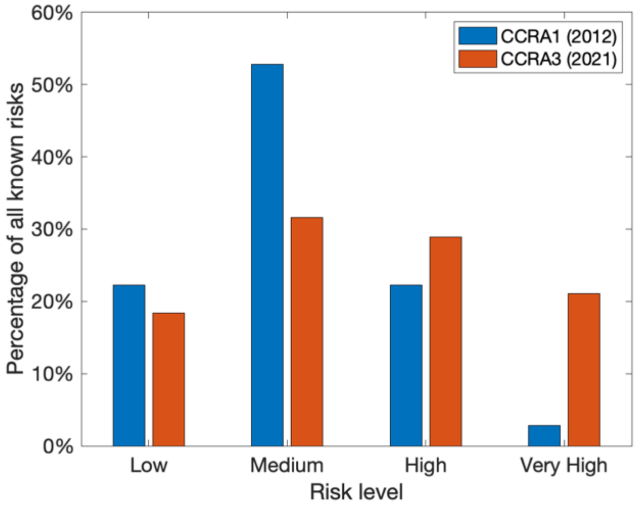

Figure 9 The distribution of risks across risk categories for CCRA1 (made in 2012) and CCRA3 (made in 2021). Note that the categories of risk are not the same between reports. As such, this is not a perfect mapping, but it does highlight trends in risk assessment. The risks over time have significantly increased with over 20% of risks categorized as very high in 2021. (Behrens, P., 2023 based on data from Watkiss, Cimato, and Hunt, 2021).

Of the 55 risks assessed, 13 of these have unknown costs. Unknown risks include those to aquifers and agricultural land from sea level rise and risks to business from disruption to supply chains and distribution. Further, the confidence in the CCRA3 Valuation Report is, as the report itself notes, quite low overall due to the difficulties in making such assessments, the limited funding allocated to the assessment, and the paucity of academic research on valuation across many areas. Out of the 42 risks for which a valuation was assigned and confidence assessed, around 85% were assigned as ‘very low’ or ‘low’ confidence. Only one was given a high confidence level – “risk to businesses from flooding”, for which over £1 billion of damage per year is assessed by 2050.

Further, the CCRA3 itself also highlights new research regarding the potential for a single tipping element, the Atlantic Meridional Overturning Circulation (Ritchie et al. 2020). A rapid slowing and potential collapse of this current could have even more dramatic impacts on the agricultural sector than was previously projected. Other impacts include changes in the north Atlantic jet stream, accelerated loss of Antarctic and Greenland ice sheets, permafrost thaw, and reduced carbon uptake by the biosphere (for example due to increasing wildfires).

An economic assessment from the London School of Economics estimates that hard-to-quantify catastrophic economic risks could be, on aggregate, larger than well-known risks (Rising, Dietz, et al. 2022). There are very large uncertainties (see the black error bars in Figure 10), but average damage estimates are 7%-8% of annual welfare-equivalent GDP. Remarkably high given that UK economic growth has been around 1-2.5% per year on average over the last few decades. Even under high mitigation median estimates range around 2-3% GDP damage annually by 2100.

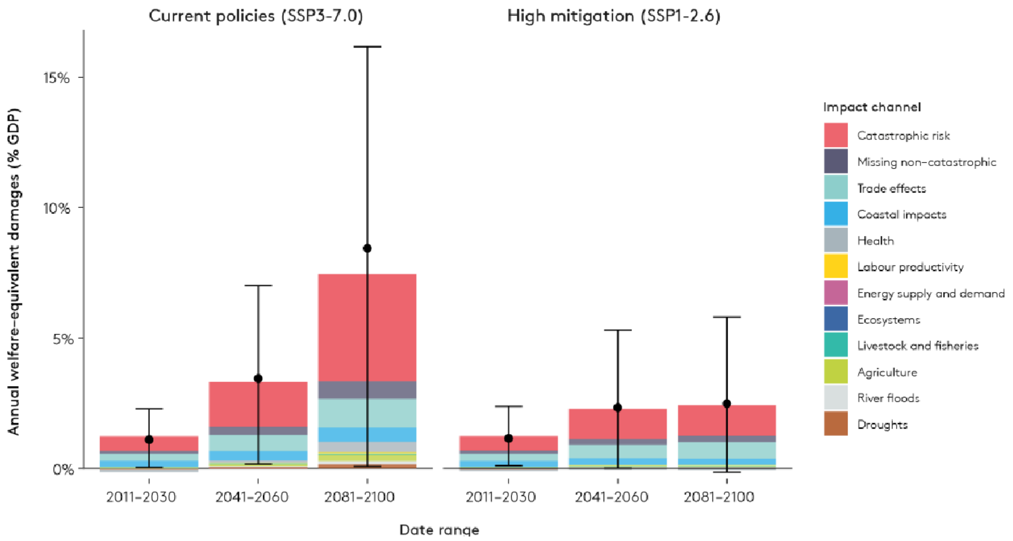

Figure 10 Annual welfare-equivalent damages as a percentage of GDP over time for current policies and high mitigation policies. Note the large exposure to catastrophic risks and that approximately half of all non-catastrophic, well-known damage is from international impacts of climate change on trading partners (Rising, Dietz, et al. 2022).

1.3 Study approach

There are abundant 'missing climate risks' that are currently unaccounted for in any model (Rising et al. 2022). However, even with these uncertainties we can assess various trajectories for food, energy, and infrastructure and research can give indications about how the cost of living may develop across a basket of goods. This report will qualitatively assess impacts across different sectors using the impacts we see today and scientific literature on future trends. It will also assess how mitigation and adaptation influence costs. It will also explore whether moving faster towards climate and environmental goals would be economically beneficial.

What does cost of living include? The cost of living covers only basic expenses, such as housing, food, energy, health, and taxes. It does not include other costs such as luxury consumption or government expenditures – although the latter may indirectly impact the cost of living via taxes. In general, the cost of living also excludes the direct environmental costs from activities that drive climate change - often called externalities. An example of an externality is the significant health costs of air pollution from agriculture and fossil fuels (Landrigan et al. 2018; Lobell, Di Tommaso, and Burney 2022). Although air pollution is not accounted for in national accounting, it does have a real-world impact on healthcare costs that does increase the indirect cost of living via taxes. Many efforts to address food and energy system GHG emissions would involve large reductions in air pollution, reducing current and future indirect costs and associated cost-of-living. Estimates for this impact are extremely uncertain and these uncertainties are explored further below.

Climate impacts on household expenditure and cost of living can be broadly characterised in four different ways:

1) **Direct costs**, for example installing and running an air conditioner or uninsured losses in floods.
2) **Indirect national costs**, for example the loss in economic productivity due to high outdoor summer temperatures or transport interruptions due to extreme weather.
3) **Indirect international costs,** for example increases in cost of food due to yield losses in countries that supply the UK or damage to international ports that export goods to the UK.
4) **Wellbeing costs**, for example non-market costs such as mental-health impacts from displacement after flooding or air pollution from wildfires.

This report surveys these impacts for each sector in the sectoral overview which include Food, Energy, Health, and Built Infrastructure. Food and Energy are the two sectors that will see the largest system transitions and choices in food and energy policy in the coming decades will have deep impacts on health and the built environment.

How has cost of living changed? The cost of living has increased dramatically over recent years, driven by broad economic impacts resulting from COVID, conflict in Ukraine, and climate change. Climate's signal on the cost of living may be hard to separate from shorter-term factors such as war or supply chain problems and it will not be climate impacts that dictates the cost of living alone. However, climate impacts serve as a continuously increasing pressure on social systems that means that future shocks become worse, increasing economic costs further. Ultimately, mounting ecological pressures can cause societal upheaval and eventually collapse (Tainter and Taylor 2014).

There have been several reports investigating the impact of climate change on the UK economy, but very few on cost of living. Reports on the economic impacts of climate change include the Valuation Reports of the CCRA (Watkiss, Cimato, and Hunt 2021), and most recently a report published in 2022 on projected overall climate damage (Rising, Dietz, et al. 2022). A report exploring climate change impacts on cost-of-living in the UK was produced in 2016 which used CCRA1 costs as an input.

How do climate impacts on cost of living relate to mitigation and adaptation efforts? Recent increases in the cost of living can be seen as a result of conflict in Ukraine driving energy and food prices higher. But they can also be seen as a failure to move fast enough in building a cleaner, greener energy and food system. For example, a large proportion of the inflation experienced over 2022 was driven by fossil fuel price increases driven by the Russia-Ukraine conflict. This means that countries that have moved slower in decarbonising their energy system have seen greater relative increases in overall energy costs. While wind and solar saved the EU €12 billion in additional gas costs between March 2022 and January 2023, the savings could have been larger if the bloc had moved faster to net-zero (Brown 2023). This report will include a survey of the mitigation and adaptation costs. It will also assess, where possible, whether more rapid net-zero transitions in energy and food would be cheaper than slower transitions.

As described above there are many economic externalities that impact cost-of-living such as the health costs due to air pollutants in energy and agricultural systems. These 'costs of living' are substantial and offer large opportunities in lowering overall cost of living even in future scenarios. There is growing evidence that the steps needed to transition energy and food systems to net-zero would be cheaper than continuing in the same arrangements as today in both economic and non-economic welfare costs.

Scenario approach

There are many future climate scenarios used across the literature. They are generally based on a level of warming by a specific year and include scenarios for socioeconomic development over time. The differences between scenarios generally become important in the second half of this century, when the differences in temperature between scenarios are larger. By 2050, the differences between low-, medium- and high-emission scenarios are generally smaller. As this report focusses mainly on near-term costs to 2050 it will draw from a wider selection of research using different scenarios (Watkiss, Cimato, and Hunt 2021). However, it should be noted that economic costs can become extremely large for some warming scenarios by 2100, in the order of 7% of GDP annually (Rising, Dietz, et al. 2022).

UK Climate Scenarios The Global Circulation Models (GCMs) that provide large-scale modelling of physical climate change have reasonably coarse resolutions of 60-300km, meaning they cannot capture smaller local features (i.e. land use type or topography) and atmospheric processes (such as convective storms). The UK Climate Projections (UKCP) provide a resolution 12km (for UKCP18, improved from 25km in previous projections). Even at this higher resolution, some weather formations such as the convective storms common in UK summers are not represented. As such there are separate convective climate models that have resolutions down to 2.2km that show reasonable agreement with historic extreme storms (Met Office 2019).

UK Climate Projections assess a range of plausible warming scenarios this century (1.5, 2, 3, and 4 °C). Projections indicate that the UK will likely warm faster than other regions in the global models. The UKCP18 shows indications of more severe warm temperature impacts but at a slightly lower overall temperature compared to UKCP09. Further, updated UKCP18 projections show lower levels of precipitation with more potential for winter drying (Tim 2020). These overall trends have important implications for agriculture in the UK and the potential abandonment of agricultural land. These may be exacerbated even further in the event of tipping elements in ocean currents. This will be revisited in the sectoral overview.

1.4 Economic costs, cost of living, and distributional impacts

There is a "hierarchy of uncertainty" in making climate change assessments (see Figure 11 for an overview). Uncertainties that feed in at one level of assessment are inherited by the other levels. For example, the estimates of economic impacts rely on previous assessments of environmental impacts that include several uncertainties that in turn rely on estimates of temperature increases that include other uncertainties. These uncertainties are often not well appreciated and contribute to the concept of 'missing risks' in climate change risk assessment described above (Rising, Tedesco, et al. 2022b).

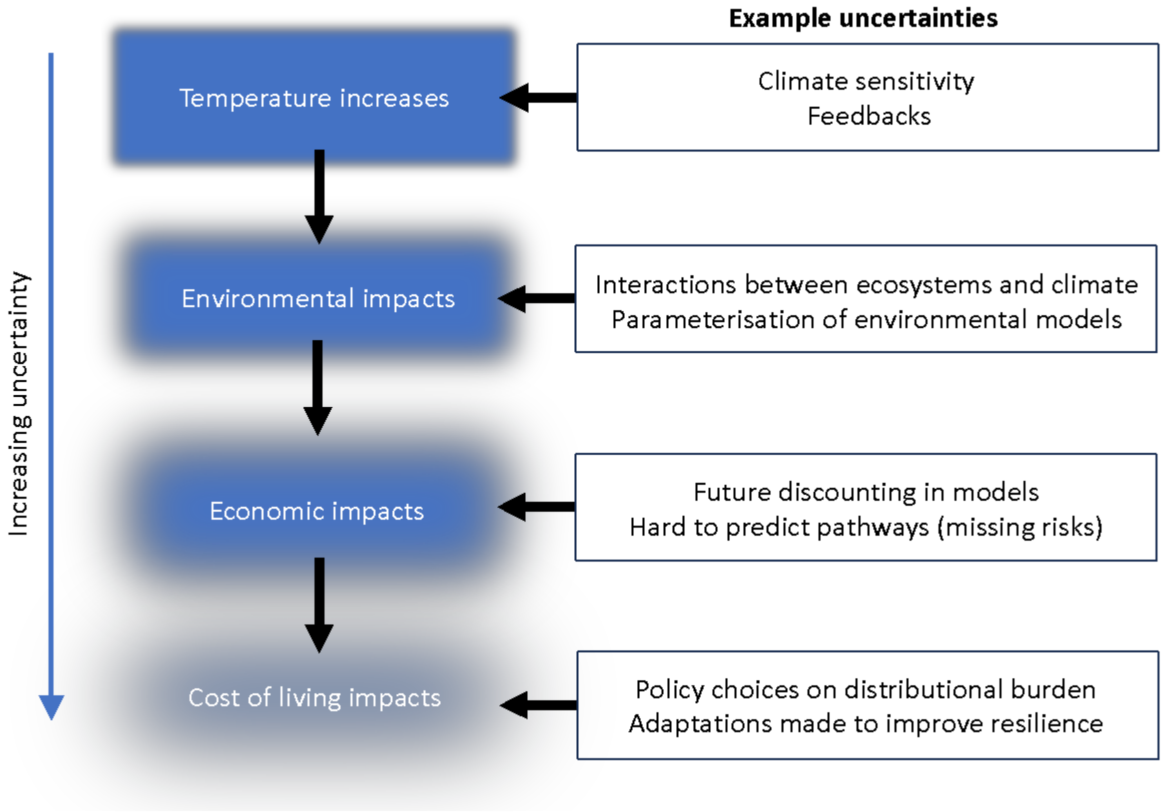

Figure 11 The hierarchy of uncertainty in climate change impact assessments. As assessments move from temperature to environmental impacts to economic impacts to impacts on cost of living our uncertainty increases dramatically.

We can be most certain about overall average temperatures with a given emission trajectory. Even reduced-complexity approaches using a handful of tuned equations can make remarkably accurate projections of future temperatures. However, as we have seen, the way in which natural systems equilibrate to these temperatures is more uncertain and there has been a systemic underestimation of the rate of change. This complicates matters for impact assessments.

Even if research were able to be very precise about the rate of change, timing, and scale of flooding, there would still be a large uncertainty over how individuals, communities, and countries would respond and what pre-emptive measures they might take to adapt to these changes. As such, the impacts on society are then even more uncertain. The cost of living experienced by different groups in society will also depend on government choices surrounding which sectors and which communities shoulder the greatest economic burden. This uncertainty does not preclude analysis, but it is essential to consider when examining potential impacts.

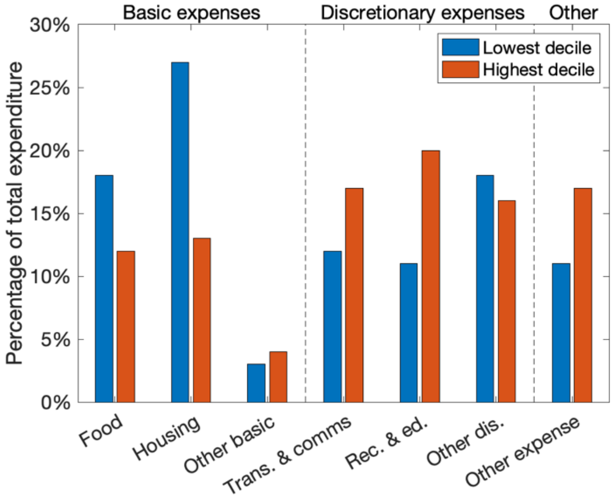

Figure 12 Expenditures across the lowest and highest 10% of income earners split by broadly basic and discretionary expense groupings. 'Other basic' includes clothing and health. 'Trans. & comms' is expenditures for Transport and Communications, 'Rec. & ed.' Includes expenditures on recreation, education, restaurants & hotels. 'Other dis.' Includes expenditures on household goods & services, alcoholic drinks, tobacco & narcotics, and other goods & services. 'Other expenses' includes money transfers, instalment payments, licenses, and other spending (Behrens P 2023 based on ONS data 2022).

In general, increases in the cost of living will be felt very differently across income brackets. The top 10% of income earners spend less on basic goods as a proportion of their total expenditure than the bottom 10% (see Figure 12). The bottom 10% of income earners spend between 5 and 12 percentage points more of their income on the two core components of cost of living, food, and housing (which includes household energy costs). Any increases in the absolute level of these costs have more pronounced impacts on the lowest 10% of income earners.

However, it is not only that lower income groups spend more money on basics costs as a proportion of their total expenditure, but low-income groups are also more exposed to direct climate impacts. For example, lower income groups are more exposed to flooding, both because they are more likely to live in areas prone to flooding and because they are less likely to hold insurance that would pay for flooding damage.

In the next sections we survey the changes in food, energy, health, and infrastructure due to climate change. We assess the economic costs of these changes and where possible impacts on cost of living. We then explore the opportunities in mitigation and adaptation and, finally, explore whether moving faster to a more sustainable future would lower costs.

2 Climate impacts on cost of living by sector

The sub-sections below provide a sectoral overview for the direct, indirect, and international costs of climate change. Where possible assessments are given to 2050 under current policies. Each section then concludes with the costs and benefits of mitigation and adaptation, along with an exploration of whether faster action than national targets could increase or lower cost-of-living.

2.1 Food

Overview Climate change will have broad impacts on UK agriculture both globally and domestically. The UK is a large food importer, importing 46% of consumed food in 2020 (DEFRA 2021). The EU is the UK's largest food trading partner, providing a further 34% of consumed food (together producing 80% of total consumed food). However, it's UK imports food from further afield as products embedded in EU products, for example grain from Ukraine fed to Danish bacon which is then imported to the UK. Given its dependency on food imports, the UK is heavily exposed to climate risks to agriculture in Europe and worldwide. As with other trends, climate impacts are now expected by many to hit food supply faster than previously expected (Harvey 2023b).

> *The next big shock to our food supply will almost certainly be caused by climate change in the form of extreme weather events and catastrophic harvest failures.*
>
> National Food Strategy, 2021

The UN's Food and Agriculture Organization (FAO) provides a global food price index which tracks the price of a basket of food commodities. In 2022, it reached historic highs, driven by climate impacts, conflict in Ukraine-Russia, and avian flu (see Figure 13). These record food price highs were above the price during the 2007-2008 food crisis which drove global unrest (Bellemare 2015). In 2022, an estimated 12,500 protests across 148 countries were recorded related to food, fuel, and cost-of-living increases (Hossain and Hallock 2022). Many countries such as Ecuador, Argentina, Albania and others have seen unrest due to food insecurity (Euronews 2022; Rojas-Sasse 2022; Valencia 2022). While the food price index has dropped below 2022 levels, as of early 2023 it remains high, food prices continue to threaten food security, and April 2023 saw a small increase (FAO 2023).

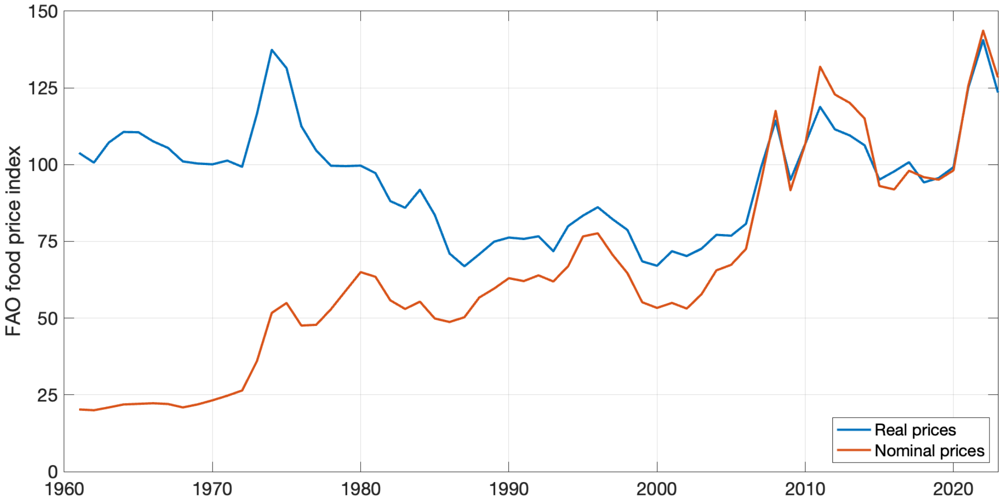

Figure 13 Food price index over time in real and nominal prices. Nominal values are in current prices while real prices are adjusted for inflation (Behrens, P. 2023 using data from FAO, 2023).

The UK has seen a rapid rise in food prices driven by 1) national and international climate impacts, 2) the high cost of inputs such as energy and fertilizer, driven by the Ukraine-Russia war and 3) Brexit trade frictions. Climate change and oil and gas prices drove the majority of food price inflation (88%) and total overall food costs were up 14% over one year (Energy & Climate Intelligence Unit 2022). For energy costs, these increases were not driven by supply-side increases in the cost of production, but profit seeking by energy companies. This is different in the food system, where energy input costs have increased. Most recently, in early 2023 many vegetables saw price increases of 15-40% from the previous year and shortages due to the combination of drought in Southern Europe and Brexit issues (Smith 2023). Some of the highest overall cost increases have been seen for animal products. While meat has seen an average 15% rise compared to bread and cereals at 17%, milk and cheese have seen increases of 30-40% (ONS 2023). Beyond climate and conflict impacts, avian flu has had impacts on poultry and eggs (it is important to note that this is also driven and perhaps caused by unsustainable farm animal practices)(Baur 2023)

Climate impacts on food production and interruptions to food trade have been estimated to increase a family's food bill by 9% with a range of 0% to 28% by 2050 (the top of the range was attributed to a very high emission trajectory) (Watkiss et al. 2016). A recent study surveying crop models showed that climate change is likely to have greater impacts on agriculture earlier than thought (Jägermeyr et al. 2021). The study found yield decreases in some crops and increases in others. However it is important to note that there are many potential impact pathways, both nationally and internationally, that are not generally accounted for in economic or crop models, including agricultural pest spread and the role of tipping elements in altering precipitation (Deutsch et al. 2018). Other studies have found significant impacts of extreme weather events on all major cereal crop yields (Gaupp et al. 2019; Caparas et al. 2021; Kent et al. 2017). As a result, current expectations of climate damage to agricultural systems are probably underestimated.

Climate impacts on food costs will fall disproportionately on the poor. The average UK non-retired adult spends 14% of their total expenditure on food with those with the lowest income spending 18% compared to the highest at 12% (ONS 2022b). These dynamics are already visible across various indicators, for example a report from the Independent Food Aid Network that found that 91% of organizations like foodbanks reported increased need in the year from November 2021 and in autumn-winter 2022. Over two thirds of these organisations experienced supply issues. Approximately half these organisations were concerned about their capacity to support people if demand stayed the same or increased (IFAN 2023).

In addition, healthy and nutritious food is often more expensive, with one estimate suggesting it costs an average £8.51 for 1,000 calories compared to just £3.25 for 1,000 calories of less healthy foods (Goudie and Hughes 2022). The same report found that healthier foods are also increasing faster in price than less healthy food. The distributional effects of this are stark, 20% of households would have to spend nearly half their disposable income on food to follow the government-recommended healthy diet while the wealthiest 20% would need to spend just 11%. Joined-up Government policy, such as that suggested in the National Food Strategy, is desperately needed to address existing access to nutritious food while ensuring that the burden of any increase in food costs during a food system transition is not felt disproportionately by those on lower incomes. To ignore increasing food prices due to climate damages and the current inequalities in the food system is a political choice.

There are very large opportunities of a food system transition that would reduce emissions while improving climate adaptation, human health, and biodiversity. The largest opportunity is in increasing the share of plants in diets could simultaneously reduce emissions while improving public health and food security. It could also spare land that could be used to rewild and help buffer against extreme weather events (Sun, Scherer, Zhang, et al. 2022; Sun, Scherer, Tukker, et al. 2022; Behrens, Jong, et al. 2017). This is because 71% of UK land is used for agriculture (over 100% when land used for the production of imported food is included), the largest component of which is beef and lamb pastures (see Figure 14). An area almost the size of Scotland could be repurposed as a result of a transition to healthy diets. This would also have large benefits on other environmental harms such as biodiversity loss, water pollution, air pollution, and more.

Such a food system transition would almost certainly be economically beneficial and reduce overall costs for consumers and the National Health System. Estimates of the current hidden costs of the UK food system ranges between £40 billion to £94 billion per year, with the majority driven by health costs. The food system is also heavily subsidised at around £2.4 billion per year of which less than 1% is currently spent on the Sustainable Farming Initiative (DEFRA 2023) and an estimated 80% of which is spent on animal agriculture (Kortleve et al. 2023). Finally, there is a 'trophic loss' in calories and protein when crops are fed to animals. Growing these crops for direct consumption, especially legumes which generally have environmental and human health benefits would reduce overall costs.

Integrative and multidisciplinary government policies such as those recommended in the National Food Strategy will need to be sequenced to help producers shift activities. Government interventions will also be needed in the middle of the food supply chain to prevent supermarket monopsonies applying downward pressure on producers and prices. Addressing power imbalances in the food supply chain will be vital. There is little research on the speed of potential consumption shifts in food system transitions, but there is some evidence of sustained dietary transitions (the area with the largest consumer-led opportunity) with reductions in meat intake in analogous countries with Germany seeing reductions of around 15% in per capita meat intake over 5 years (Euronews 2023).

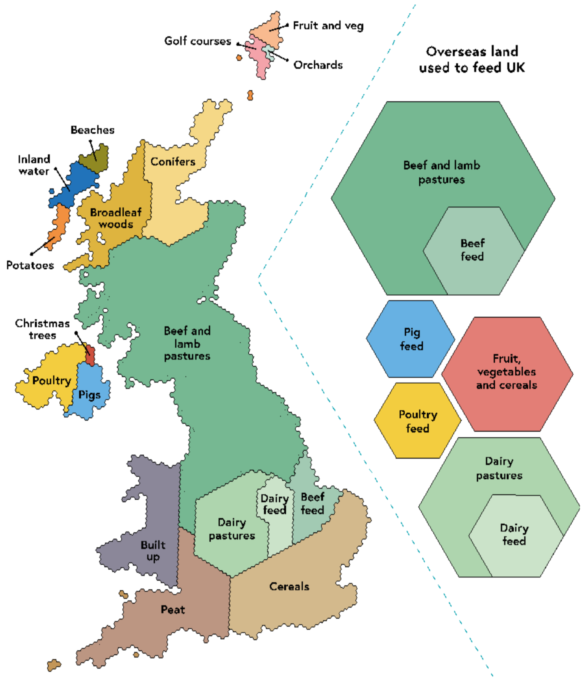

Figure 14 Land use in the UK and land used in the import of products from other countries. The large amount of land used for animal agriculture presents an large opportunity for mitigation and adaptation options if shifts to more plant consumption were possible. (National Food Strategy 2021)

Direct climate costs The UK has seen increasing climate impacts over the last decade. For example, 2020 saw 40% declines in UK wheat yields due to heavy rainfall and droughts during the growing season (DEFRA 2021). Recent record heatwaves of over 40°C in 2022 followed by heavy rainfall and flooding may lead to potato harvests falling by 50% (Horton 2022). The western European drought was estimated to be at least 20 times more likely by climate change (Schumacher et al. 2022). Negative impacts have also been seen in livestock animals, with impacts on sow fertility, diary productivity, and more, due to input price increases and impacts of high temperatures on animals (Levitt 2022; McDougal 2022). Overall costs to agricultural productivity are shown in Figure 15.

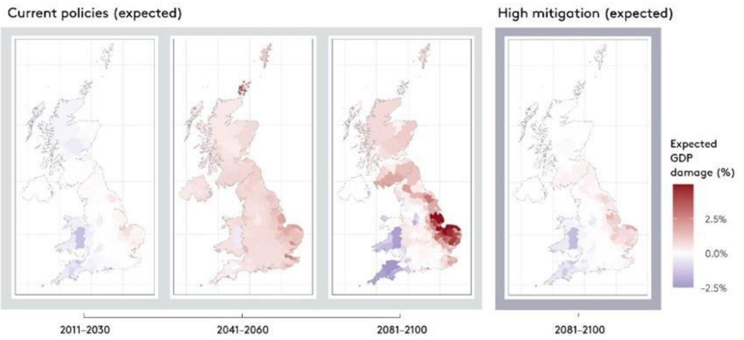

Figure 3.2.b. High-risk costs of agricultural productivity by region of the UK, 2011–2100, under current policies and high-mitigation scenarios (% of local GDP)

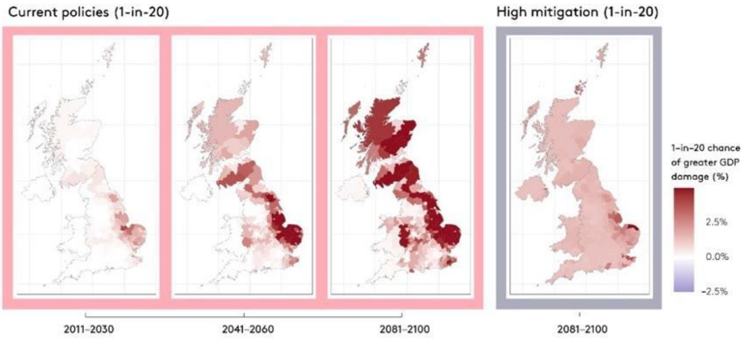

Figure 15 Top row: Potential costs to agricultural productivity across the UK until the end of the century given current policies and a high mitigation effort. Bottom row: high-risk costs to agricultural productivity, that is a 1-in-20 chance tail risk of climate change impacts (Rising, Dietz, et al. 2022).

Research on future UK crop yields is mixed. Some work suggests that UK agriculture may benefit from warmer overall temperatures and general economic estimates vary from a small net benefit to damages of £16.7 billion per year to 2050 (Rising, Dietz, et al. 2022). However, many studies rely on historical analogues for extreme weather events that may be inappropriate given the emergence of unprecedented climate extremes (Slater et al. 2022). Further, research does not generally account for potential tipping elements that can impact UK food production – for example precipitation impacts – due to the complexities of such modelling.

Studies that do examine tipping elements find that their impacts on precipitation and agriculture are substantial. In fact, the overall impact on UK agriculture may be largely influenced by the level of changes in one specific tipping element – the AMOC[4] ocean current (Ritchie et al. 2020). The AMOC transports heat from the tropical regions to the UK, resulting in a climate around 3-7°C warmer. Melting freshwater from Greenland driven by climatic changes can slow or even stop this heat transport.

Ritchie et al. (2020) investigated the agricultural and economic impacts of an AMOC collapse, finding a widespread cessation of arable farming with agricultural losses an order of magnitude larger than climate impacts without this tipping element. These losses are driven by precipitation reductions which would lead to less moisture in the UK particularly in summer, exacerbating drought (Jackson, Bloomfield, and Mackay 2015). The level of climate adaptation in climate change is highly dependent on the ability to irrigate crops (Rosa et al. 2020).

However, there are large uncertainties, if the AMOC continues climate change would likely provide greater arable production, increasing agricultural benefits by £40 million per year by 2080. This turns into

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[4] The Atlantic Meridional Overturning Current (AMOC) is a large-scale transport of heat through the Atlantic Ocean, it forms part of a very large system of currents around the world's oceans. Transporting heat from the the tropics northwards to Europe it is responsible for the temperate climate of Western European countries.

an estimated £346 million per year loss if the AMOC ceases. The critical factor is the availability of water and Work finds that water restrictions across England and Wales will become more severe, more frequent, and longer in the future with the potential for significant agricultural impact (Salmoral et al. 2019). Other tipping elements may present agricultural issues, for example coastal flooding of farmland due to accelerated Antarctic melting driving sea level rise. However, these impacts are likely to be much lower than the impact of AMOC on UK agriculture (Hanlon, Palmer, and Richard 2021).

Climate impacts will also worsen for farm animals and fisheries. There were numerous impacts on animal agriculture during 2022 heatwaves, including the deaths of millions of factory farm chickens in industrial farm sheds that saw temperatures of up to 45°C (The Independent 2022). Increased temperatures stress animals and results in reductions of milk production, growth, and reproduction, along with an increasing range of animal-related diseases (Godde et al. 2021). For example, a vector-borne disease of livestock, bluetongue, is now moving further north in Europe due to climate change and is simulated to move into almost all areas of the UK by the 2080s, a 1 in 20-year outbreak today will become the norm by the 2070s under higher-temperature scenarios (A. E. Jones et al. 2006). Further, farm animals and other farm runoff drives algal blooms which, under higher temperatures, can result in marine death, impacting fisheries. Rising, Dietz, et al. (2022) estimates some costs of climate damages to UK livestock and fisheries (excluding beef and poultry and other areas of damage including diseases) at around £630 million per year under current policies by mid-century (assuming a static economy and relying on work from L. et al Jones (2020)). These estimates are considered a "considerable underestimate".

Indirect climate costs There are several pathways that climate could impact food costs, mainly via difficulties in the food supply chain. For example, the flooding of food processing infrastructure or greater requirements for refrigeration in the cold chain. Other examples could include impacts on human productivity across food production activities. These impacts are hard to model, likely to be much smaller than the national and international climate impact and will be partially covered in the sections on health and infrastructure below.

International climate costs As mentioned above, while recent global crop models show that climate impacts on agriculture are emerging earlier than thought (Jägermeyr et al. 2021) which show some increases in yields for some crops, the overall picture is negative. However, extreme weather events are only partially included in a smaller selection of the models used in this report and other work has found that the frequency of global multi-breadbasket failures due to extreme weather events is also set to increase. Gaupp et al. (2019) found that the most sensitive crop, maize, historically experienced failures every 1 in 16 years, which increases to 1 in 3 years at 1.5°C and 1 in 2 years at 2°C – very likely for 2050. Other crops also see the largest increases in multi-breadbasket failure by 1.5°C with smaller, but still increasing chances at 2°C. Similarly, Caparas et al. (2021) found that crop yield failures could be as much as 4.5 times higher by 2030 and up to 25 times higher by 2050 across global breadbaskets.

As the EU is a major contributor to the UK's food security, it is worthwhile examining climate impacts across Europe. The most recent AR6 IPCC assessment report found that heat and drought will lead to agricultural production losses over most European areas this century, and that potential gains in Northern Europe would not offset these losses (Bednar-Friedl et al. 2022). Although irrigation can prevent large agricultural losses, the report also warns that adaptation via irrigation will be limited by water availability as the continent warms. Ben-Ari et al. (2018) find that multiple extreme weather events leading to large wheat losses will become 12% more frequent by 1.5°C in France, which produces 20% of EU yields.

A significant further threat is the increasing range of agricultural pests due to warmer temperatures. There is already evidence that climate change has expanded the geographical distribution of pests (FAO 2021). Deutsch et al. (2018) found that global yield losses to insects of major grains due to population growth and metabolic rates could increase by 10% to 25%, with the largest increases across Europe. For instance, France sees insect pest losses increase around 50% for both wheat and maize. The combined effect of insects and other agricultural pests such as diseases, weeds, rodents, and mites are largely unknown.

Although economic-agricultural models include aspects of trade tariffs, model runs do not generally include export restrictions which can increase international food prices. For instance, the World Bank estimated that export restrictions throughout 2022 as a response to the Russian invasion of Ukraine increased the price of staple foods like wheat, rice, and soybean oil by 9% or more (Espitia, Rocha, and Ruta 2022). This was on top of inflationary pressures due to supply shortages. Future trade restrictions as a response to climate impacts on regional food yields could have impacts on staples imported to the UK.

Benefits of mitigation and adaptation Increases in food expenditures will depend not only on the rate of climate impacts on agricultural systems, but the speed of adaptation and mitigation. A food system transformation is essential for meeting national net-zero and biodiversity targets (IPBES 2018; Tilman and Clark 2014). Current food system emissions alone could breach 1.5°C and even 2°C (Clark et al. 2020; Ivanovich et al. 2023). That is, even with substantial shifts in the energy sector, food systems alone could account for the rest of the emission budgets for these critical thresholds. Studies repeatedly show that this transition requires three main approaches 1) a shift to plant-based diets, 2) reductions in food waste, and 3) improvements in the environmental impact of production. However, research generally shows that plant-based diets represent the largest opportunity, followed by food waste reductions (EAT Forum 2019; World Resources Institute 2018).

There are numerous other benefits from acting fast to mitigate food system emissions, including: improved air quality, water quality, increased resilience, access to nature, biodiversity, and more. These hidden costs of the food system globally have been assessed in multiple studies and are roughly estimated at between US\$6 – US\$20 trillion each year depending on the study. One study estimated current externalities of \$19.8 trillion, double the current global food expenditure of \$9 trillion (Hendriks et al. 2021). In a UK assessment, The Sustainable Food Trust estimated that for every £1 spent on food the UK consumer pays around another £1 in hidden costs (Fitzpatrick et al. 2019). Overall estimates for the hidden cost of UK food range between £40 billion to £94 billion per year (National Food Strategy 2021). The largest proportion of this across multiple studies are driven by health costs (40% to 72%), generally followed by environmental costs (10% to 48%). A food transition would help avoid a large proportion of these costs and many others and the National Food Strategy found that some plant-products as sustainable forms of high-yield farming

Since 71% of UK land is used in the food system and the majority of this is used for inefficient animal-agriculture, a UK food system transformation would save large areas of land (Sun, Scherer, Tukker, et al. 2022). Some of the least productive agricultural land – overwhelmingly for animal agriculture – sees the largest opportunity for carbon sequestration if left to nature (see Figure 16). This land could be used be spared and soils improved, enhancing carbon sequestration, biodiversity protection, recreation, and more, all while providing healthier diets. This also help address the soil compaction costs of an estimated £470 million annually across England and Wales, and soil erosion of £150 million (CCC 2021). Land sparing could also help the UK adapt to climate impacts, for example by allowing for strategic flooding, improving drought resilience via water retention, reforestation, reduction of storm surges, etc. For example, setting a proportion of flood plains aside to be strategically flooded could return over £6 for every pound spent (Dottori et al. 2023a).

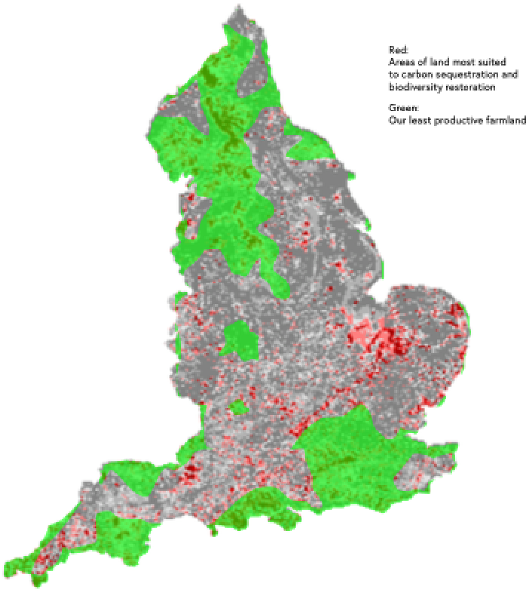

Figure 16 The least productive land (green) compared to the area most suited to carbon sequestration and biodiversity restoration (red). Small shifts in diets can allow for freeing of land to achieve both biodiversity and carbon goals while maintaining or lowering food prices. (National Food Strategy 2021)

There are many further cost benefits of a food transition unaccounted for in the above calculations, mainly connected to health costs not only related to diets. Further benefits could include reducing the emergence of viral pandemics and antimicrobial resistance (if food systems are transitioned globally)(Hayek 2022), access to nature that can improve health outcomes (Twohig-Bennett and Jones 2018), animal welfare benefits and human mental health issues from working in slaughterhouses (Scherer, Behrens, and Tukker 2019; Slade and Alleyne 2023), and biodiversity improvements that have difficult-to-model impacts on health.

Even with today's food subsidy system that proportionally supports meat proteins over plant proteins, some consumer survey and modelling studies have found that a shift to plant-rich diets would be cheaper for the consumer in high-income countries like the UK (Springmann et al. 2021; Rao et al. 2013; Pais, Marques, and Fuinhas 2022). One modelling study found costs 22%-34% cheaper for plant-based diets in high-income nations, dropping to over 50% cheaper by 2050 under a full food system transition including food waste reductions (Springmann et al. 2021). Some work finds that while planetary health diets could benefit farmers overall in a shift to fruits and vegetables due to higher prices, they may cost the consumer 29% more by 2050 due to these high prices (Rieger et al. 2023). However, this analysis did not include subsidies, additional policies, or potential changes in production in response to higher prices. Such a supply-side shift for farmers moving to different products would benefit from Government spending on skills and labour programs as well as policies to buy out existing animal producers. Finally, if such a shift is pursued holistically there is also evidence that such diets would improve resilience to international food price shocks, increasing food security. For example, a plant-rich shift across Europe would almost compensate for all production deficits from Russia and Ukraine (Sun, Scherer, Zhang, et al. 2022).

The 16 recommendations in the UK's National Food Strategy in 2021 represents the best holistic package of efforts to drive a system shift in the UK food system that could help adapt to climate change, limit health costs, and support those employed in food production (National Food Strategy 2021). These recommendations would have direct and indirect cost-of-living. For example, sugar and salt taxes recycled to subsidize fruit and vegetables, helping farmers move to sustainable land use, and repositioning subsidies to encourage change. The shift to more plant-rich diets would allow farmers to save land and switch to environmental payments for environmental land management if those payments are high enough to support communities.

Is a faster food transition cheaper or more expensive? Although a food system transformation is likely to lower cost-of-living directly through food prices and via health and other impacts, it is unclear whether faster transformations of the entire system would result in changes in cost-of-living. In contrast to rapid energy transitions, there is very little empirical work examining this specific question for the food system. There is evidence that healthy diets equating to more sustainable food systems are already cheaper than the alternatives today and clearly a reduction in food waste would reduce overall food bills (Springmann et al. 2021).

However, overall costs to the food system that may have indirect impacts on cost-of-living depend on the speed of transition. Despite broader national health and environmental benefits, faster changes in rural economies may mean more upheaval and costs than a slower one. It would also lead to more stranded assets – agricultural assets that are depreciated before their expected end of life. There are already investor concerns surrounding these stranded assets (George 2022). One EU study found that the impacts of a food transition shift are highly heterogeneous across regions (Rieger et al. 2023) which German pig and poultry farms potentially seeing income losses of more than 30% and vegetable farmers seeing a more than 30% increase. However, studies have not included subsidies which change this picture significantly and may be used to reduce labour and business issues.

Moving faster towards a food transition would result in a faster shift to healthier diets, which can have significant short-term medical improvements (in the order of 2-12 months), especially for those suffering from non-communicable diseases such as cardiovascular disease or diabetes (Taheri et al. 2020; Juraschek et al. 2020). Habitat recovery and biodiversity protection can also have significant benefits in the short term. For example one UK rewilding project found a 41% increase in tree vegetation and a six-fold increase in areas covered with shrubs over two decades (Schulte To Bühne et al. 2022). As such, the benefits from food system transformations could accumulate quickly, saving money for the NHS and reducing overall increases in taxation and welfare-costs of disease.

This transition will require significant policy changes, support for those who may lose out in this transition, and fundamental shifts in subsidies. However, as of 2021, the Climate Change committee found “there is no clear evidence that climate risks or opportunities for agriculture and forestry are being strategically planned for or managed (CCC 2021).

2.2 Energy

Overview The overall costs of UK energy will very likely be dictated more by the speed of transition to net-zero rather than the impact of climate change. A well-organized net-zero energy transition is expected to be a win-win, reducing both direct energy costs and climate impacts. International competition in clean energy technologies is also increasing rapidly with the Inflation Reduction Act in the US and the Green New Deal in the EU funnelling trillions of dollars into the energy transition. The UK is yet to respond with a similarly ambitious vision.

> *It is essential that the UK acts quickly and decisively. There is a new global race to maximize the growth potential from net zero at a time of wider geopolitical uncertainty. We are now at a crunch point where the UK could get left behind.*
>
> Mission Zero, The Skidmore review, 2021

There will be several important direct climate impacts on the energy system, including additional demands for building cooling, exposure of coastal energy infrastructure to storms and sea level rise, changes in wind speeds that impact wind power generation, heat impacts on transmission and distribution grids (including electrical substations), and water availability for the cooling of fossil fuel plants and hydropower operation.

The largest overall climate costs may arise indirectly from power outages either due to water availability for cooling powerplants or, more likely, infrastructure damage resulting from extreme weather events. Interruptions to power availability have particularly high levels of downstream economic impacts. For instance, while £1 of direct damage to telecommunications infrastructure results in £1.41 of overall economic damage, this jumps to £2.36 total economic damage for every £1 direct damage in the energy system (Pant et al. 2020). That is, the costs of electricity system damage more than doubles during power outages due to the loss in economic activity.

The average UK adult spends around 7% of their income on energy (including petrol for personal transportation). The lowest income earners spending 10% and the highest 5%. As with food expenditures, the poorest communities are most exposed to cost of living impacts on energy prices (ONS 2022b). Greater domestic production of energy, for example via renewable energy systems, will likely have a very stabilizing effect on future prices and inflation (Melodia and Karlsson 2022).

There are very large opportunities in energy system mitigation and adaptation. Due to rapid declines in the cost of renewable energy and electrified technologies (such as electric vehicles and heat pumps) a faster global transition to net-zero energy systems is very likely cheaper by 2050 rather than 2070 (Way et al. 2022b). Work has estimated that a fast energy transition would save $12 trillion globally compared to no transition, and over $7 trillion compared to a slow transition (see Figure 17)(Way et al. 2022b). This finding is on a purely economic basis, not including indirect benefits such as health benefits from reduced air pollution. However, this does not account for the many social and political frictions in guiding such a transition, or policy mistakes that may raise costs. For example, if solutions such as hydrogen for home heating are pursued which are much more expensive than direct electrification via heat pumps. The period between the transition from one system (fossil fuels) to another (wind & solar dominated) has been called the 'mid-transition' in which many mistakes can be made which result in further costs in the future (Grubert and Hastings-Simon 2022). In the example of hydrogen for heating, the construction of infrastructure may result in a 'path dependence', consigning communities to higher costs for energy into the future and higher costs of living.

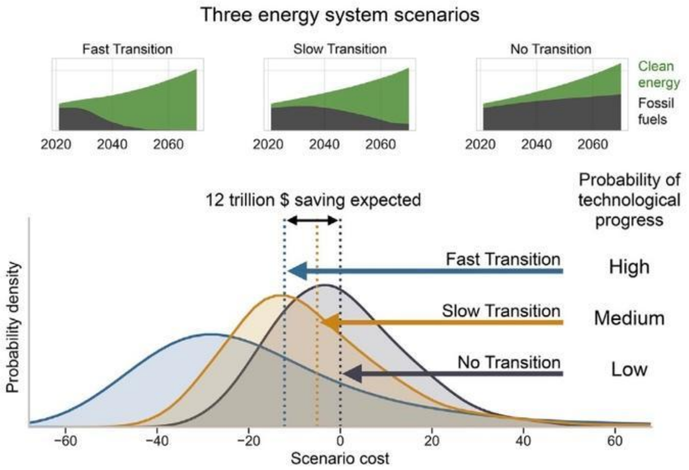

Figure 17 The probability of different costs in different global energy system transition scenarios. There is uncertainty about the future costs of the transition, but the average estimate of system cost is that a faster transition is cheaper than a slower transition which, again, is cheaper than no transition at all. (Way et al. 2022b)

Given the economic and non-economic burdens of today's energy system it is possible that an even earlier transition – by 2030 or 2040 – would see lower costs to consumers overall. In 2020, the UK's Climate Change Committee found that savings from a net-zero transition in the energy system (and building sector) begin in the early 2040s even with pre-Ukraine war energy prices and for a central scenario (i.e. middle-of-the-road assumptions for behavioural change and technological improvements)(CCC 2020b). However, a quicker transition in the 2030s might be constrained by the level of capital and labour required. For example, even with the current net-zero target by 2050 an estimated

135,000 and 725,000 net new jobs would be created by 2030 (CCC 2023). The higher end of the estimate represents a workforce larger than the number of full-time UK teachers at 624,520 (BESA 2023). This level of labour expansion requires very large training programs and coordinated labour market policies. A target earlier than 2050 would see even higher labour requirements. If policymakers are serious about international targets, organizing to overcome these limits is essential. There are also ways to make the overall scale of the transition smaller and there are many demand side measures for reducing the overall size of the UK energy system. For example, Barrett et al. (2022) found that demand options for meeting zero-emission targets could reduce overall energy demand by 52% without compromising on citizen's quality of life.

There are also concerning signs that the UK is falling behind in the international race for the clean energy market. There is some academic evidence of a macro-economic first mover advantage by building competitive advantages over other world regions (Karkatsoulis et al. 2016). Benefits of a first mover advantage can include: labour benefits as companies focussing on Net Zero are more likely to attract and retain talent; greater investment from industries as one of the greatest commercial uncertainties is changes in policy; greater opportunity for high value-added exports, and more. Against the backdrop of the $748 billion Inflation Reduction Act in the US and the €600 Green New Deal across the EU, the UK's political commitment to net-zero appears to be flagging with the failure of recent offshore wind auctions (Savage 2023), commitments to new oil and gas licences (Scott 2023), and concerns of a significant lack of leadership (Harvey 2023a)

Direct costs The largest potential for direct cost-of-living climate impacts in the energy system is the demand for heating and cooling. Heating demand currently comprises around 75% of UK household energy consumption (Watson, Lomas, and Buswell 2019). While climate change will increase cooling requirements during the summer, this will likely be more than offset by the decrease in winter heating requirements. Watkiss et al. estimated climate benefits to heating by the 2020s using 2013 energy prices at around £87 per year (with a range of £38-£135), rising to around £135 by 2050. This, compared to a to total household energy expenditure in 2013 of £500. Given energy price inflation due to Russia-Ukraine conflict these benefits are likely significant. However, the opportunities for improving energy efficiency in buildings and electrification via heat pumps will have a larger impact on overall heating bills.

Climate change will also impact the availability of water used to cool thermal power plants (mainly gas, coal, nuclear) (Behrens, van Vliet, et al. 2017; van Vliet, Vögele, and Rübbelke 2013; Van Vliet et al. 2016). As of the 2010s, roughly 40% of renewable freshwater was used to cool powerplants around the EU and power availability in Europe has already seen climate impacts on availability (Behrens, van Vliet, et al. 2017).Renewable energies require much less water in operation and a renewable energy transition will lead to lower requirements on water (Jin et al. 2019). However, two important types of low-carbon generation in the UK will require continued water availability: nuclear power and hydropower. UK nuclear power in uses sea water so is less exposed to climate issues compared to the river-cooled nuclear generators in France. The climate impacts on UK hydropower are mixed and depend on the models used. There was a loss of approximately £29 million due to a drier summer in 2018, which could become more common. The latest UKCP18 projections suggesting more drying than in previous projections (Watkiss, Cimato, and Hunt 2021). Hydrogen also requires water to produce and if it plays a large role in future energy systems it could present water issues. For example research in the United States suggest it could be a significant freshwater demand – at 7.5-10% of current energy system demands by 2050 (Grubert 2023). There may also be climate impacts on future windspeeds across the UK and the North Sea but these impacts are uncertain and research has found both positive and negative impacts (Després and Adamovic 2020; Hdidouan and Staffell 2017).

Indirect costs While some of the direct costs above will change household energy bills, there are numerous other pathways where goods and services increase in price due to higher energy input costs. Many of these costs derive from indirect impacts from infrastructure damages discussed further in the built infrastructure section below. A good example is the damage to substations due to flooding during

2009 which has been estimated in direct costs as £50 million (up to £300 million) in 2009 prices (Thacker et al. 2018).

International indirect costs The UK is exposed to international fossil fuel markets and interruptions via to climate change with approximately 50% of gas, 10% of crude oil, 50% of diesel, and 50% of jet fuel imported internationally in 2022 (DESNZ and DBEIS 2022; 2022). Even if the UK were completely self-sufficient, fuels are traded on international markets and the UK would still be exposed to energy price fluctuations driven by global climate impacts. For example, hurricane Harvey, a historically powerful storm, hit major refinery facilities in Houston in 2017 and had global impacts on oil price (Wald 2017; Chokshi and Astor 2017). One study allocated around two thirds of the economic damage to the enhancement of the storm due to climate change (Frame et al. 2020).

In terms of electricity the UK is heavily exposed to international fuel markets that power UK electricity generators. Marginal gas generators largely set the price of UK electricity which in turn is dependent on international gas availability and prices. The UK is less exposed to direct imports of electricity than other European countries, with 10% imported in 2022, all of which is from the EU (European Comission 2021). While future fuel dependences will decrease in the future due to net-zero efforts, the transmission of electricity from the EU may increase under more optimized scenarios (Schmid and Knopf 2015). The future cost of energy will largely depend on trajectories of international energy markets and the level of decarbonization pursued in the energy system. It is likely that the energy transition will improve energy security overall, reducing inflationary pressures.

Overall economic and wellbeing cost-benefits of mitigation and adaptation It is generally believed that a deep energy transition of at least 70% decarbonisation is cheaper than continuing the current system across much of the world (Bogdanov et al. 2019; Way et al. 2022a). Technologies like solar panels are more like smartphones – which have seen rapid technological development and lower costs – than large, factory-style fossil fuel power plants which have seen very little to no reductions in cost. Renewable energy technologies have seen a remarkable decline in cost in the past 1-2 decades (see Figure 18), driven largely by the small, modular nature of these technologies allowing for fast iteration and learning in supply chains (Creutzig et al. 2017; Wilson et al. 2020). Benefits of these technologies also include better returns on research & development, faster installation, and increased social returns. By 2019, it was already cheaper to build new renewable energy systems than to continue operating existing gas and coal power stations in many regions of the world (MGI 2019). However, such a shift is very capital intensive and costs will vary in different countries depending on their renewable resources, existing housing stock, future mineral prices, and more.

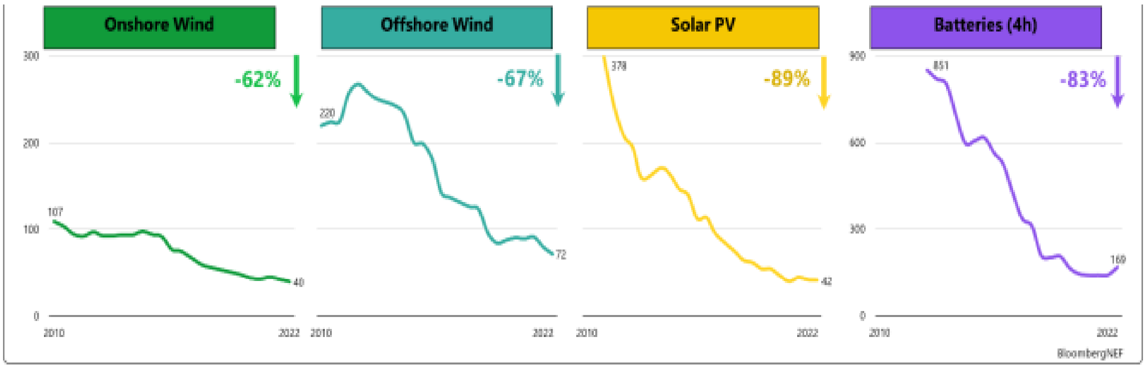

Figure 18 The global average cost of onshore wind, offshore wind, solar and batteries between 2010 and 2022 per unit of electricity generated (from BNEF).

A major reason for renewable generation' cost efficiency is that they are more capital and energy efficient in the broader energy system. For example, one BNP Paribas analysis found wind and solar energy projects with battery electricity would produce 4 to 7 times more useful energy than fossil fuel vehicles for the same capital investment (at $60 per barrel)(Lewis 2019). This is fundamentally driven by the fact that petrol vehicles waste around 80% of energy while electric vehicles waste only 20%. Generally, electrifying sectors – for example heating homes with heat pumps instead of gas – results in large energy efficiencies.

The UK net-zero energy transition outlook is even more positive given the availability of cheap and plentiful offshore wind in the North Sea, one of the best global wind resources. Future electrified systems will be cleaner, less reliant on water, and more resilient from geopolitical shocks and trade interruptions. The cost of a UK net-zero transition will be characterized by rising capital investments in the short- and medium-term, followed by substantial net savings in operational costs over the medium- and longer-term to 2050.

A 2021 Climate Change Committee report estimated the cost of reaching net-zero by 2050 at £1.4 trillion, offset by £1.1 trillion in savings (OBR 2021). These savings would continue past the 2050 horizon, compounding to large overall savings. However, many studies were conducted before the Russia-Ukraine war, underestimating the benefits of a net-zero transition. There has also been a general overestimation of transition costs over time. As Rising et al. (2022) highlight, the 2008 Climate Change Act expected an 80% emissions reduction relative to 1990 to cost 1-2% of GDP, while this dropped to just 0.3% of GDP by 2021[5]. In 2021, one study found that all methods for estimating future energy transition costs underestimated progress in almost all technologies[6] (Meng et al. 2021)

Further, these figures do not include benefits from investment, exports, job creation, and environmental improvements. All of which could impact cost of living. Examples of indirect economic benefits to the UK of a net-zero transition include the global market opportunity of £1 trillion for UK businesses and the creation of 480,000 jobs by 2030 (Mckinsey 2021; DBEIS 2022; DESNZ 2022). When accounting for some of the benefits from new jobs, economic activity, reduced reliance on overseas fossil fuels, and cost savings to household bills, some estimates suggest a 2% increase in GDP by 2050 (CCC 2020a).

Still more benefits arise from indirect benefits to health and NHS costs. For example, Rising, et al. (2022) apply a cost of life estimate of 1.83 million to a UK air pollution study showing 40,000 premature deaths per year by 2050 in the absence of an energy transition and find a GDP benefit of 0.5-0.6% of 2050 GDP (Vandyck et al. 2018). However, the air pollution study is for a below 2°C scenario and benefits could be even greater depending on the trajectory. Further, mobility shifts to biking could confer even more health cost benefits (Kraus 2021).

An underappreciated cost to current energy systems is noise pollution in urban centres. Research is still ongoing and estimates of harm are uncertain. Early analysis found that the annual social cost of urban road noise in England could be between £7 billion to £10 billion, a similar size to the cost of road accidents £9 billion (DEFRA 2014). This noise would be reduced with electrified transport and modal shifts away from cars to bikes and walking.

Another environmental benefit with economic consequences includes improvements to agricultural yields through the reduction of energy system air pollution. Nitrious Oxide emissions from vehicles can reduce crop yields with one study finding 10% increases in winter and summer crops in western Europe from a 50% reduction in Nitrous Oxide emissions (Lobell 2022). The UK has reduced Nitrogen Oxide pollution over time and there are likely to be benefits translating to lower costs of living (but no study has shown this yet). There may be other, benefit-pathways by which a net-zero transition will provide improve cost-of-living.

However, while the overall picture of costs and benefits is positive, there are different policy choices that may increase costs faced by the consumer. Delays in the implementation of emission mitigation measures has been estimated to result in higher overall transition costs in modelling studies (Victoria et al. 2020;

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[5] These estimates were also calculated before the Russia-Ukraine war.

[6] Based on studies published before 2020.

Way et al. 2022a). One recent, clear example was the cutting of several energy efficiency subsidies and the changing of energy regulations by the Cameron government that overall added an estimated £2.5 billion to UK energy bills (S. Evans 2022). Later updates suggested this could have grown to £9.8 billion given increases in energy costs (S. Evans 2023). Many of the subsidies that were cut were for improving buildings' energy efficiency would have reduced energy consumption while improving indoor temperatures having important benefits for the health system. The poor building quality in the UK and lack of insulation was estimated to directly cost the NHS £1.4 billion per year in colds, flu, and pneumonia, with a further cost of £18.5 billion per year for the long term cost to society of leaving people in poor houses (Garrett et al. 2021).

Other delays in policy or poor policy choices can also raise costs. For example, the current push for green hydrogen use in heating is very likely to end up costing more than electrification of heating via heat pumps. Studies have repeatedly found heating with green hydrogen could cost multiples that of heating with heat pumps across the EU (Weidner and Guillén-Gosálbez 2023; Rosenow 2022). This is largely due to the overall efficiency of delivering heat via the two different systems (see Figure 19).

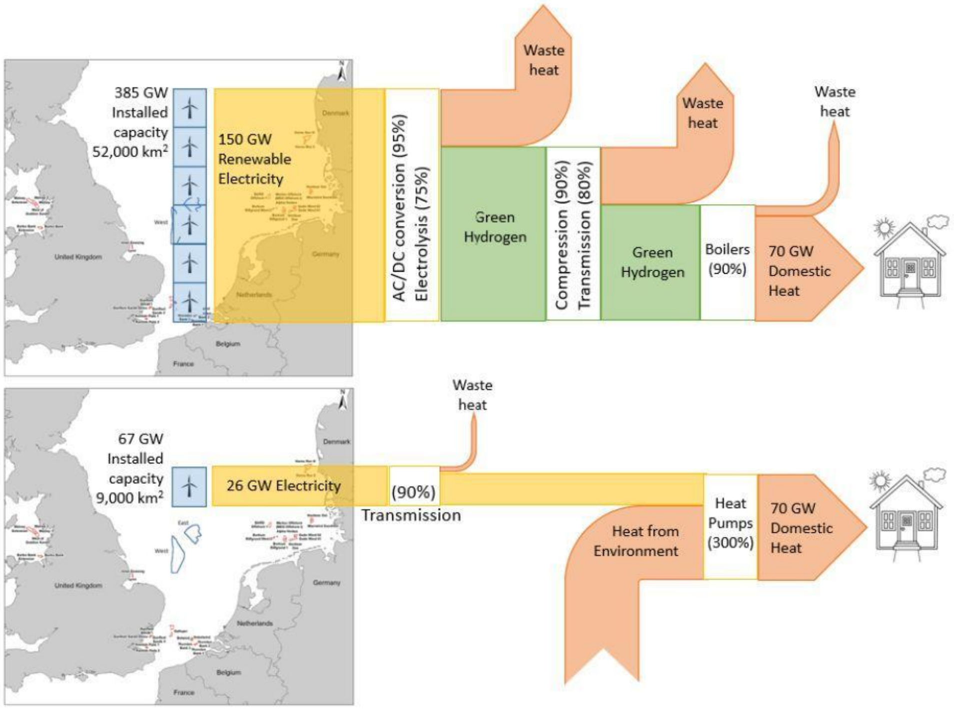

Figure 19 The two scenarios of providing UK heating with green hydrogen or heat pumps. Arrow colours show energy carrier: electricity, hydrogen, heat. Widths of arrows are proportional to the flows of power. Blue boxes show wind turbine farm area on the map. Red polygons on the maps are existing offshore wind turbine installations currently totalling around 10GW. Visualisation and description from David Cebon at the Hydrogen Science Coalition.

Other costs may arise from poor policy sequencing or missed opportunities in integration across the energy system. For example, research suggests that electric vehicles could supply all the necessary short-term storage requirements for grids across the world by as early as 2030 but this is only possible if the required regulatory, market and technical incentives and standards are aligned (Xu et al. 2022). In the UK case, work by Ofgem suggests that a well-planned integration of heat pumps and batteries would save £4.7 billion overall (Millard and Oliver 2023).

There are other uncertainties that can have an impact on the costs of the energy transition. For example, there may be policy and geopolitical challenges in maintaining access to the raw materials needed for electric vehicles and other technologies needed in the energy transition (Grubert and Hastings-Simon 2022). While there are very likely sufficient raw materials for the energy transition, access to them may be hampered by geopolitical tensions which may increase their price and subsequently the relative cost of living changes from the energy transition (S. Wang et al. 2023).

Is a faster energy transition cheaper or more expensive? A global net-zero transition by 2050 is likely cheaper than by 2070 based on market costs alone, with a median estimate of $12 trillion in global savings (Way et al. 2022a). When including non-market costs such as air pollution it is even cheaper. Some analysis suggests that the cost of delaying action by ten years could double the cost of net zero (OBR 2021). There is evidence that a faster transition before 2050 would be cheaper but forecasts are challenging. For instance, the 6th Carbon Budget in 2020 from the UK's Climate Change Committee made an analysis of net-zero costs and savings (CCC 2020b). They found that savings would start to accrue between 2040 and 2045 for a central, 'balanced' scenario (see Figure 20). However, this was produced before energy price increases from the Russia-Ukraine war. A Cambridge Econometrics report found that the net-zero transition would result in a GDP 2-3% higher by 2050 (Cambridge Econometrics 2020).

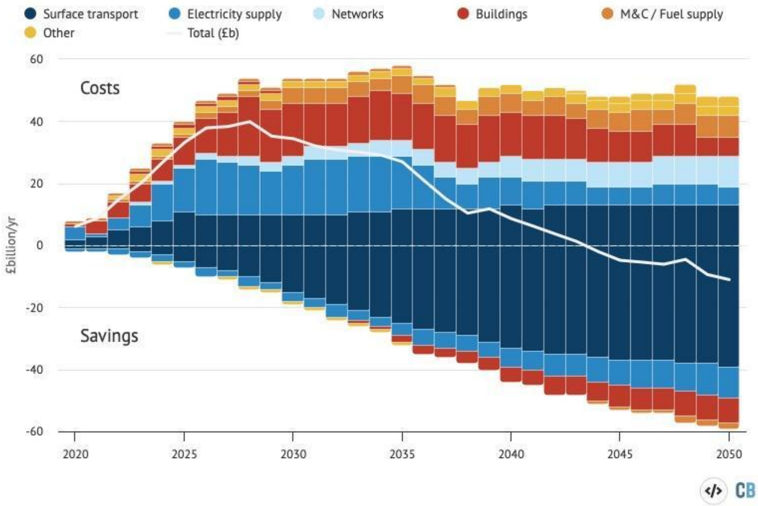

Figure 20 Costs and savings of a net-zero transition by 2050 as calculated by the Climate Change Committee in the 6th Carbon Budget Advice. These values are prior to Russia's invasion of Ukraine and are calculated on a central, 'balanced' pathway. Data from (CCC 2020b). Visualization by Carbon Brief (Gabbatiss 2023)

If non-market costs are included, it is highly plausible that an even earlier transition is cheaper given that the costs of air pollution alone – largely driven by energy system emissions – are of a similar magnitude to transition costs (Landrigan et al. 2018). However, if considering economic costs alone the overall economic impact of a faster transition would depend on the cost of borrowing for the large-scale infrastructure needed.

2.3 Health

Overview There are a wide variety of climate-related health costs and benefits to society, including the cost of resourcing the NHS, opportunity costs due to disability, and the pain and or suffering due to physiological impacts of climate change (both mental and physical). Direct economic impacts on cost of living will be smaller than other sectors given the public provision of healthcare via the NHS. However, there will be significant direct welfare costs from flooding and heatwaves causing mortality and disability.

> *Up to 90% of hospital wards could be at risk from overheating due to their design, while 10% of hospitals are located in areas of significant flood risk*
>
> The Third United Kingdom Climate Change Risk Assessment, 2021

There will also be indirect climate impacts due to future changes in taxation to fund the NHS and other social care. Other indirect costs include the loss of productivity due to extreme weather events, or the longer term wellbeing impacts of mental health problems (Watkiss et al. 2016). While the health impacts and disruption from these events can sometimes be put in narrow economic terms, it is important to remember that the impacts on individuals, families, and communities are often impossible to place in purely monetary terms.

National health impacts will be driven mainly by temperature exposure to both cold and heat extremes, communicable diseases, and injuries from extreme weather events such as floods. For example, the 2020 heatwaves have been estimated to drive 2,500 excess deaths, predominantly among the elderly (Public Health England, 2020). A similar number of excess deaths were recorded over the 2022 heatwaves[7] (ONS 2022a).

Indirect impact pathways on UK cost of living from health impacts on overseas populations are exceptionally hard to model and why modern climate modelling includes additional, uncertain costs. A recent example is the move by Spanish authorities ban some outdoor working for agricultural workers due to extreme heat conditions which may increase the costs of agricultural production and therefore food imported to the UK (Reuters 2023). It is hard to assess these difficult-to-map pathways but they may have cost of living impacts in the aggregate.

Health costs from climate impacts will have different distributional effects than for food and energy given that health costs are socialized via the NHS. There is little difference in direct proportional healthcare costs across income groups. However, lower-income groups typically see a worse quality of NHS care in England, have higher rates of existing medical issues, see greater exposure to heatwaves, and see greater vulnerability to flooding (Nuffield Trust 2020; OHID 2022; Rizmie et al. 2022; DEFRA 2012). The vulnerability to heat and cold-related events is higher for the elderly, especially those in low-income households which have reduced access to cooling and face higher proportional energy costs. Lower income workers may be exposed to increasing outdoor heat temperatures in manual work. Climate change interacts with the domains of health inequality in multiple different ways (see Figure 21). For example, the spread of diseases can disproportionally impact already vulnerable groups.

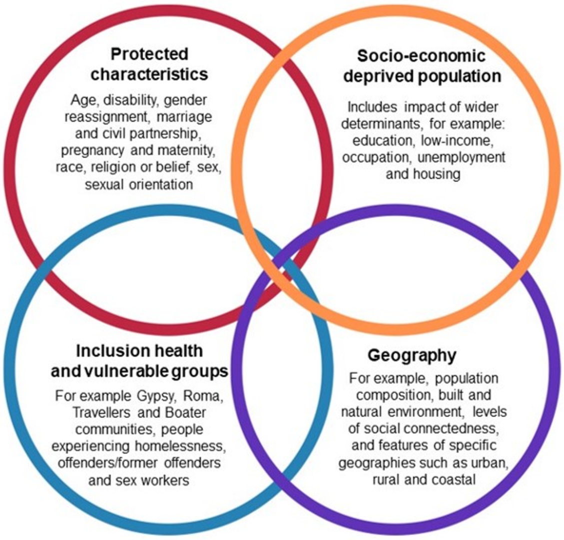

Figure 21 Domains of health inequality as adapted in (OHID 2022). Climate change impacts interacts heavily with Geography and can exacerbate underlying issues in communities across the UK.

The health sector is not a large contributor to overall emissions. However, mitigation of emissions in other sectors – for example improving the energy efficiency of buildings or shifting to healthier diet – will have

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[7] when controlling for COVID deaths and other factors.

significant healthcare impacts. Further, climate adaptation has significant impacts on overall resiliency and economic healthcare costs for communities exposed to flooding.

Direct impacts While increased temperatures will increase excess mortality from heat-exposure in the summer, warmer winter temperatures may drive decreases in excess-mortality from cold-exposure. Almost 12 million people in the UK are exposed and vulnerable to summer heatwaves. The 2018 heatwaves resulted in an estimated 8,500 heat-related deaths and the heatwaves themselves were made 30 times more likely due to climate change. There is disagreement in the literature as to the overall balance of these effects in the UK. Some find overall benefits, others find that the increases in heat-related mortality are already larger than the reductions in cold-related mortality (Rising, Dietz, et al. 2022; Feyen et al. 2020; Bressler et al. 2021). Research suggests that while cold-related mortality will continue to outweigh heat-related mortality in overall numbers, the gap will narrow in the future (Hajat et al. 2014).

Floods also drive direct climate costs via fatality and injuries. Floods throughout 2020 saw the largest number of annual deaths from flooding since similar records began in 2010. In England, deaths totalled 111, 274 hospitalizations and 422 injuries (Lancashire Evening Post 2021). Using standard approaches for translating equivalent welfare losses using the value of a prevented fatality, costs of these floods were over £200 million with further costs from hospitalizations, injuries, and long-term care (DfT 2023).

Indirect impacts Healthcare costs in general may rise significantly via indirect impact climate pathways. Higher temperatures have been associated with increases in hospital admissions in England and Wales, amounting to over 12,000 additional admissions per year in recent years. While cold admissions have decreased, the net change is an increase in over 8,000 additional admissions per year (Office for National Statistics, 2022). At an estimated cost of a hospital admission of £1176 (2017 prices) results in overall additional cost to the NHS of approximately £9.5 million per year as of 2022 (Rizmie et al. 2022).

There may also be additional health impacts from extreme weather on mental health with research showing increased stress and both from the flood event itself and disputes with insurance and construction companies (Greene, Paranjothy, and Palmer 2015; Carroll et al. 2009). These losses can also drive a loss in a sense of place and identify. Flood displacement for a longer period can drive additional harms. Residents who were displaced for over a year after the 2013-2014 floods in England were significantly more likely to experience PTSD, depression and anxiety (Waite et al. 2017; Munro et al. 2017). The overall welfare costs from this stress is not well studied.

Warmer temperatures will increase the possibility for insects and ticks spreading diseases across Europe (Semenza and Suk 2018). In the UK, these diseases may include malaria, West Nile fever, dengue fever, Chikungunya fever, leismaniasis, Lyme disease and tick-borne Encephalitis (Baylis 2017; Chin and Welsby 2004). Standing water from the additional flooding can provide a breading environment for several of these diseases along with typhoid fever, cholera leptospirosis and hepatitis A (WHO 2005). There are currently no known economic assessments of the health burden of future disease spread in the UK.

Overall labour productivity due to increasing outdoor temperatures in the UK is expected to fall slightly due to rising air temperatures driving fatigue and cognitive performance. Previous work suggests that economic losses from productivity loss in a scenario of low mitigation efforts could be between £9 and £31 billion by 2041-2060 based on today's GDP, with very large regional variation (Rising, Dietz, et al. 2022). However, this may underestimate impacts on indoor labour and direct losses to the welfare of workers. The authors suggest that total welfare losses through the "labour productivity channel are likely to be considerably greater". There are several other climate impact pathways that reduce labour productivity, such as the destruction of infrastructure, which will be covered in the next section.

There are further indirect impacts not usually included in assessments such as the air pollution costs from wildfires. One 2020 study found overall health costs of £21 million from a single moor fire in Saddleworth near Manchester (Graham et al. 2020). Another indirect effect not usually included is increasing violent crime and other behavioural changes due to increasing temperatures (G. W. Evans 2019). There are many other underexplored pathways such as the health costs due to the nutritional change and knock-on dietary impacts of food under climate change (Giulia et al. 2020). For example, antimicrobial resistance, driven largely by use in animal agriculture, is estimated to result in 300 million preventable deaths worldwide by 2050 at a cost of around $100 trillion (Review on Antimicrobial Resistance 2014). Resistance can also increase with increasing temperatures although the impact is currently thought to be quite small overall (MacFadden et al. 2018)

Indirect international costs The impacts to UK cost-of-living from climate-impacts on health in other countries is exceptionally hard to anticipate. The most likely pathway would be health costs in countries from which the UK imports that subsequently increases the costs of goods. An example of Spanish agricultural producers needing to stay indoors due to higher temperatures is given above but many of the indirect pathways outlined above are similar for other countries. These pathways can have cascading impacts via overall productivity losses across different sectors. It is impossible to explore all these pathways which is another reason why studies are now including an ‘unknown’ category for further climate costs.

Overall economic and wellbeing cost-benefits of mitigation and adaptation The main health benefits of mitigation are described in the energy and food system transformations described above. Examples from those sections include lower health costs due to improved diets (from a food system transformation) and lower air pollution (from an energy system transition). The size of direct mitigation opportunities of the health sector is very small in comparison to other systems as emissions from the health sector are mostly from energy consumption. Healthcare and the NHS only comprises 4-5% of national emissions (BMA 2023).

However, there are many adaptation options that can dramatically reduce human health impacts. These mainly relate to reducing the impact of flooding and heatwaves and often means urban greening that can help improve outcomes for both by absorbing floodwaters and providing lower urban temperatures. Analysis across 11 UK city regions alone estimated the benefits of urban greening was almost £300 million per year for these regions alone via avoided productivity losses and reduced cooling costs (CCC 2021).

Along with urban greening, reverting rural areas to potential natural vegetation (either via rewilding or other approaches) can help absorb flood waters while providing more access to nature. Due to the size of the food system this must go together with food system transformation in order to create the space for such access. Access to nature has been consistently shown to lower stress levels and will have significant impacts on health care costs. Health benefits from outdoor recreation in the UK has been placed at between £6.2 and £8.4 billion in 2020, with urban green-space accounting for 50% of this benefit. Increasing the availability of outdoor recreation and urban green-space would lead to further reductions in health costs.

Benefits and costs of faster transitions As noted above, current energy and food systems already place a huge burden on the health system and by mitigating their emissions through system transitions. This highlights the significant need for a joined-up policy approach towards climate change mitigation and adaptation, one that considers these healthcare costs along with costs and benefits within other systems. Given the sheer diversity of health impacts faster transitions result in lower overall costs to the health system.

2.4 Built environment

Overview Climate impacts such as sea level rise and extreme weather events can damage infrastructure across many sectors including housing, transportation, commercial real estate, machinery, and energy. These events can be particularly costly as they destroy infrastructure which facilitates economic activity and can take many years to rebuild or migrate, depressing economic output over the longer term. This is central to the discussion about the form of damage and the type of macro-economic climate change modelling described in the Introduction.

The UK is most exposed to increasing flooding risks and extreme rainfall events such as after storm Desmond in 2015 will become more frequent (Bednar-Friedl et al. 2022). Today, flooding costs between £1 billion and £3 billion per year with businesses, residential properties, transport, and utilities experiencing the largest damage in general (in descending order of value) (Environment Agency 2018; Watkiss, Cimato, and Hunt 2021). All countries will see increasing flood damage across Europe but the UK will see one of the largest increases (Dottori et al. 2023a). The UKCCRA3 found that without adaptation annual flooding damages for non-residential properties are set to increase by 27% by 2050, and 40% at 2080 if a 2 °C target is met, which increases to 44% by 2050 and 75% by 2080 if warming is 4 °C by the end of the century (Betts and Brown 2021). Other extreme weather can also cause issues for building integrity, including drought that can lead to subsidence and wind damage. These impacts are forecast to be much smaller than those for flooding.

> *The current National Adaptation Programme fails to match the scale of the challenge now facing the country. It lacks a clear vision. It is not underpinned by tangible outcomes or targets. It has not driven policy and implementation across Government.*
>
> Climate Change Committee, 2023

Direct cost of living impacts are reflected by increasing insurance costs and uninsured damages to possessions or infrastructure. Think tanks and academic research have estimated that 10,000s to 100,000s of homes are at risk of being uninsurable as they are built in at-risk areas (Gardiner 2020; Halliday 2020; Hampton and Curtis 2022). Thousands of homes are still being built on floodplains across England (Hodgson 2019). Indirect costs include damage to utility networks such as electricity, transportation, communication, and others (see Figure 22). In several cases, economic damage from power outages can be larger than the direct infrastructure costs. Every unit of direct loss in infrastructure damage must be multiplied by larger factors for indirect downstream impacts. Indirect international costs are exceptionally hard to estimate, but supply chains are vulnerable to many climate impacts. For example, international ports will see increasing challenges due to extreme weather events and rising sea levels which may increase the overall cost of goods (Izaguirre et al. 2020).

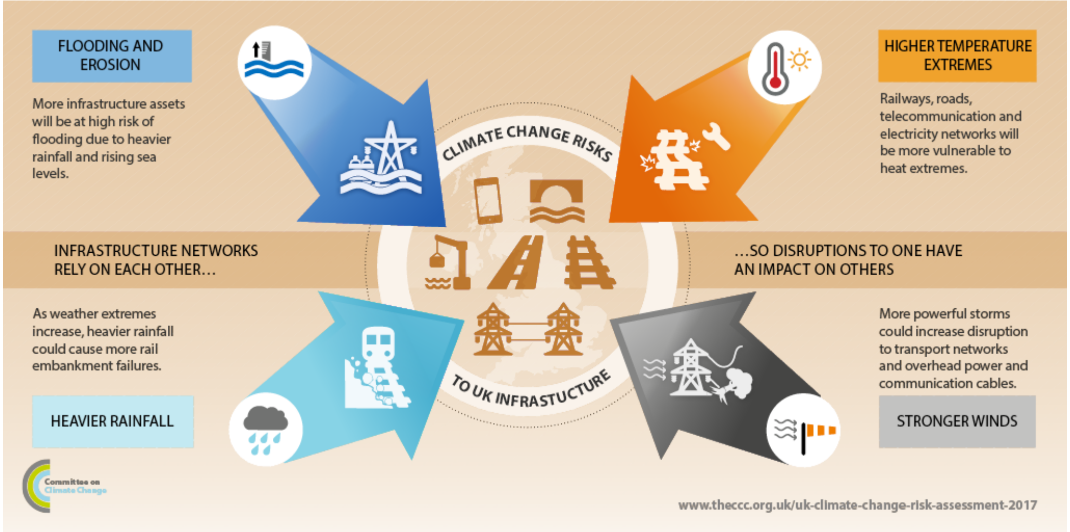

Figure 22 The different pathways of infrastructure damage in the UK resulting from climate impacts. Infrastructure damage can cause cascading economic risks and ultimately increases in the cost of living (The Second UK Climate Change Risk Assessment, 2017)..

Costs are not borne equally, especially for flooding impacts. As Watkiss et al. (2016) highlights, coastal communities are more exposed to coastal flooding where there are higher correlations between risk and deprivation (DEFRA 2012). Previous work on flood risks highlights that the proportion of deprived areas seeing higher flood risk increases faster than the overall population risk. However, not only do the flood risks increase the adaptive capacity of poorer regions is also lower. Further, as Watkiss et al highlight that in 2010 almost 40% of people in the lowest decile had no insurance compared to 2% in the highest decile group (ABI 2013). This is unlikely to have changed in the intervening years.

Although flooding is especially acute in the UK, adaptation results in very high cost benefit ratios (Dottori et al. 2023a). Across Europe, the UK sees some of the highest cost benefit ratios for flood detention (land for strategic flooding). While funding is currently insufficient, the benefit cost ratio of action to strengthen flood defences, provide detention areas and floodproofing homes lies between 2.5 and 6.5. Infrastructure and building adaptation to heatwaves is harder to estimate but many interventions come at low cost that can improve many other environmental outcomes. For example, mainstreaming nature-based solutions by increasing urban green space, physical shading in public spaces, and (green spaces, parks, early warning systems etc.).

Lower income groups also suffer most during extreme temperatures due to poorer housing quality and as highlighted by a recent London School of Economics review “National policies do not yet include a maximum temperature threshold for working and other strategies only briefly mention overheating or are for guidance only (e.g. the National Building Design Code and Overheating Mitigation, Heat and Buildings Strategy).” Similar to flooding there are

Direct impacts The largest overall threat to UK infrastructure is flooding which costs insurers an estimated £714 million annually according to the Association of British insurers[8]. Research suggests that a 1 in 100 year flood event sees losses 6% greater in 2020 compared to 1990 which could grow to between 8%-37% depending on climate sensitivity and emission trajectories (Bates et al. 2023). As with other high-income nations prone to flooding, there is likely to be an unpriced climate risk and overvaluation of housing given flood risks (Gourevitch et al. 2023).

River and coastal flooding are both set to increase. River flood hazards across western/central Europe and the UK have increased by 11% per decade from 1960 to 2010 (Bednar-Friedl et al. 2022). Coastal flooding is set to increase and be exacerbated by sea-level rise. The combination of storm surges, flooding, and winds means that while 3.2 million live in areas at risk of annual coastal flooding today this rises to 5.4 million in a scenario with limited mitigation by 2100 (Kulp and Strauss 2019). It should be noted that these estimates have been systematically revised upwards over time.

Indirect impacts The monetary report for the Third UK Climate Change Risk Assessment describes many of the cascading economic risks of extreme weather events on critical infrastructure such as electricity and transportation systems. Cascading infrastructure impacts had already been identified in the second CCRA with the 2013 flooding of electricity substations at Gatwick resulting in the disruption of 13,000 travellers and costs to welfare of £3 million for that one event (Watkiss et al. 2016). CCRA3 identified many other other examples, with the flooding of substations leaving Lancaster without power for more than 30 hours (Watkiss, Cimato, and Hunt 2021).

Interruptions to services such as electricity and communications have large indirect effects. For example, a blackout for an entire region due to flooding of a substation can have knock-on economic damage for surrounding businesses. Every unit of direct loss in infrastructure damage must be multiplied by larger factors for indirect downstream impacts. For every direct loss in the electrical system, 2.36 must be allocated to indirect losses. It has been estimated that losses in economic output in a worst-case scenario

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[8] This is lower than government figures as 20% of insurers are not members of the Association, policies are generally ‘new-for-old’, and Government estimates are more complete.

could be as high as £14 million per day, around 1.9-2 times the current losses by 2050 (in a low mitigation scenario) (Watkiss, Cimato, and Hunt 2021)

These indirect impacts can have interactions with the other sectors investigated in this report, on health, food, and energy infrastructure. For example, around 10% of hospitals are located in areas of significant flood risk, along with 35 power stations, 22 clean water facilities, and 91 sewage treatment works in areas of significant coastal flood risk (Betts and Brown 2021)

Indirect international costs There are numerous, difficult to predict pathways through which climate impacts internationally can increase cost of living in the UK. Examples include impacts to energy infrastructure like the interruptions of hurricane Harvey to Houston oil refining given above. Other examples include the 2021 Malaysian typhoon, 'arguably the worst [regional] flooding in history' which damaged Southeast Asia's second-largest port at Klang, interrupting the global semiconductor supply chain and causing some manufacturers to stop operation. As one article puts it "global supply chains will be massively disrupted beyond what can be adapted to while maintaining current systems". The economic modelling of this and subsequent impacts to cost of living is very hard to even approximate.

Overall economic and wellbeing cost-benefits of mitigation and adaptation Total adaptation costs are estimated between £1 and £10 billion per year, with the higher figure coming from UK Climate Change Committee analysis. But these expenditures would generally have very large returns on investment. Focusing on flooding, the UK sees some of the highest benefit to cost ratios of flood adaptation interventions across Europe (see Figure 23). The benefit cost ratio for UK detention areas (strategic flood plain areas) under a 1.5 degree (high-mitigation scenario) is 6.5, that is for every £1 spent the benefit is £6.5 (Dottori et al. 2023b). The benefit is even higher in low-mitigation scenarios with higher temperatures by the end of the century. Strengthening dyke systems, flood proofing buildings, and managed relocation all show positive benefit cost ratios varying around 2.5 in the UK (Dottori et al. 2023a).

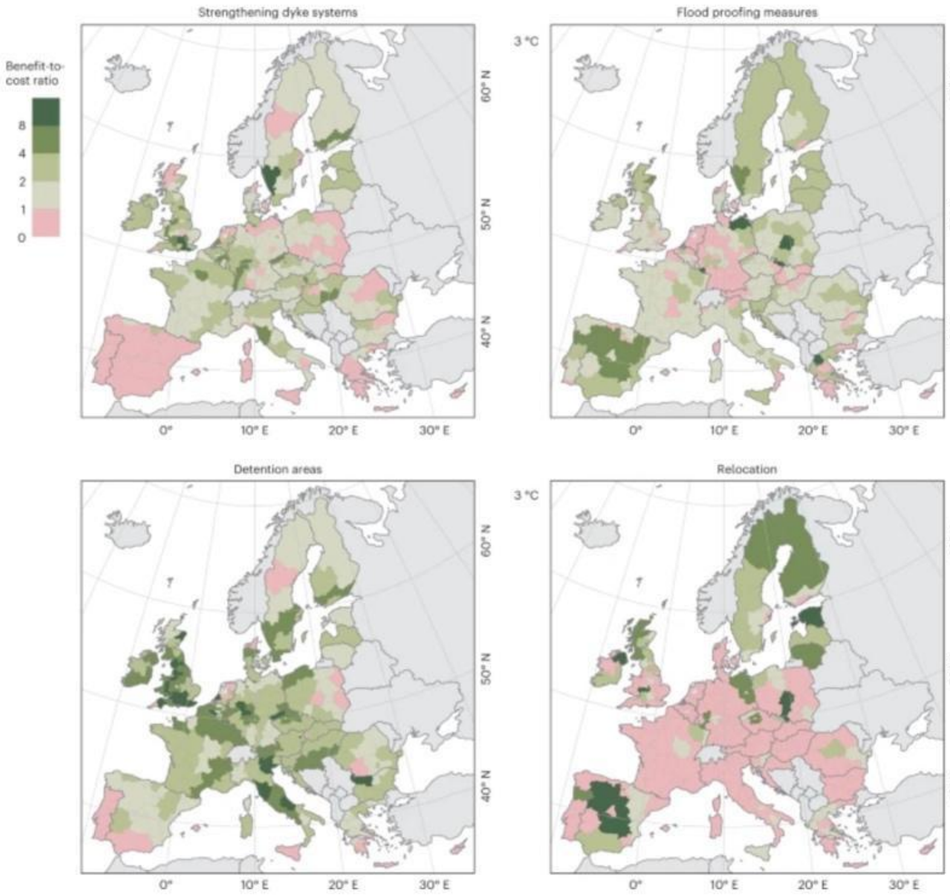

Figure 23 The benefit-cost-ratio for various flood adaptation strategies (from top left to bottom right: strengthening dyke systems, flood proofing buildings, detention areas, and relocation). The UK sees some of the highest benefits from adaptation against flooding. (Dottori et al. 2023b).

UK funding across many adaptation options including coastal erosion and coastal defence are currently insufficient and insufficient to meet older Shoreline Management Plans based on lower impacts than recent research suggests (CCC 2018). Sea level rise can cause significant further issues for coastal communities, increasing the damage from storm surges. Estimates suggest that projected economic costs in the absence of adaptation are £24.75 billion annually by 2050 but adaptation can reduce this to £3.41 billion (Rising, Dietz, et al. 2022).

Benefits and costs of a faster transition

Ovearll, the UK is far behind in preparing for the further impacts of climate change with The Joint Committee on the National Security Strategy accusing the UK Government of a “severe dereliction of duty”. On top of this, The Climate Change Committee found that no sector in England is prepared for the impacts of climate change and 2010-2020 was a ‘lost decade’ in preparation. Many of these investments are required in flood defences, as well as transportation infrastructure, and in public buildings. This lack of preparation is despite evidence of a greater concern and general willingness to support adaptation from the British public (Steentjes et al. 2020).

As adaptation efforts lag, faster transitions in the food and energy systems could deliver very large benefits for the built environment. For example, freeing land for rewilding can improve flood protection when compared to degraded land (for instance compacted pasture soils are able to absorb and store less water than natural grasslands), reducing the impacts of floods. Well executed energy system transitions can improve resilience by providing more distributed generation and off-grid power. Large wind turbine arrays can reduce the impact of storm surges and reduce wind damage. These will all have large impacts on cost of living but have not yet been economically modelled.

3 Conclusions

The impacts of COVID-19, conflict, and climate change have converged to drive consumer prices higher across the world, significantly increasing the cost of living. These compounding challenges have not only led to economic and social unrest but also underscored the urgent need for comprehensive and timely action to mitigate and adapt to the rapidly changing climate. The United Kingdom, in particular, faced recurrent strikes fuelled by grievances over the high cost of living, pay, and working conditions. These protests were not isolated incidents but rather symptomatic of a broader global phenomenon, where the rising cost of living has become a central concern for millions of people. Even with short-term emission reductions, climate impacts both in the UK and worldwide will only get worse. In the absence of rapid mitigation and adaptation these climate impacts are certain to increase the cost of living further.

Regionally, the UK, and Northern Europe have experienced climate impacts earlier than previously projected. Extreme weather events, such as unprecedented heatwaves, have become a reality, challenging the notion that temperate climates were immune to such crises. These underestimations of climate risks, both internationally and within the UK, have far-reaching consequences for communities, directly affecting the cost of living.

As the cost of living continues to rise, vulnerable communities, particularly those with lower incomes, bear the brunt of these challenges. The poorest segments of society allocate a higher percentage of their income to basic goods like food, which are most susceptible to climate-related price increases. However, higher-income groups are also beginning to experience the impacts of climate change, highlighting the pervasive nature of climate threats to society's foundational systems.

The report's findings indicate that climate change has substantial implications for the cost of living across key sectors, including food, energy, health, and infrastructure. Without effective mitigation and adaptation measures, these impacts will continue to escalate. For instance, food prices are expected to remain high, or even increase further, due to the heightened risk of multi-breadbasket failure at 1.5°C of warming. Energy infrastructure faces exposure to flooding and geopolitical tensions, while the health sector will see rising welfare losses and increased NHS costs. Infrastructure, particularly critical elements like electricity networks, is also vulnerable to climate-induced damage.

Nevertheless, the report underscores the many extraordinary benefits of transitioning to a net-zero economy. Such transitions in energy and food systems not only offer cost savings but also enhance climate resilience, health outcomes, and environmental sustainability. A rapid food system transition, for example, could reduce food costs, substantially reduce NHS costs, improve climate resilience, and create opportunities for flood adaptation and carbon sequestration. Similarly, a swift energy system transition is expected to be more economically advantageous, creating jobs and insulating the public from energy price fluctuations.

Net-zero climate mitigation policies are generally "no-regret" options, as they offer multiple benefits, including economic, health, environmental, and climate adaptation gains. These policies have the potential to limit the cost-of-living increases resulting from climate impacts. Accelerating the timeline for reaching net-zero emissions by 2040 or 2030 may offer even greater economic and environmental benefits, given the accelerating pace of climate impacts.

While an earlier transition would mean harnessing the benefits of these system transitions earlier, there are significant challenges to overcome. The cost of capital and labour dynamics will play a crucial role in determining the feasibility and cost-effectiveness of earlier net-zero targets. Further economic modelling is needed to fully assess the costs and benefits of an accelerated transition. Indeed, new or unorthodox models may be required to assess these targets.

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