Climate Change Under Fossil Fuel Intensive Development

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Headlines

Emissions

In the absence of an unprecedented change in the international community's response to fossil fuel use, there is a serious risk that emissions of carbon dioxide could raise the global average temperature by 4°C to 6°C by the end of the century. As the International Energy Agency notes, "this would have devastating consequences for the planet".

A1. The annual rounds of international negotiations on climate change have thus far failed abjectly to deliver any meaningful change in the upwards trajectory of fossil fuel use and hence emissions growth. Annual emissions in 2013 were around 60% higher than at the time of the first IPCC report in 1990; and since the last report in 2007 the global community has released a further 200 billion tonnes of CO_2.

A2. Current emission trends are tracking at or slightly above the highest emission scenario developed by the Intergovernmental Panel on Climate Change (IPCC); this is despite a deep and sustained economic downturn in the industrialised North (on a par with 1930's depression). If fossil fuel growth continues, temperatures are set to increase 4°C to 6°C by the end of the century (a temperature difference similar in scale to that distinguishing a glacial from an interglacial period, but occurring over one hundred rather one hundred thousand years).

A3. Despite significant variation in estimates of fossil fuel resources and reserves, there are sufficient reputable estimates of adequate resources to underpin high-emission scenarios in line with a 4°C to 6°C temperature rise (i.e. IPCC scenario RCP 8.5 and higher). Moreover, recent developments in extraction technologies are opening up new 'unconventional' gas, oil and coal reserves such as shale gas and tar sands.

A4. The highest of the current and previous suite of IPCC scenarios reflects emission growth slightly below 'business as usual'. No scenarios have been developed to consider the emissions (and implications) of fossil fuel growth increasing in light of accelerating levels of globalisation etc., despite this being at least as plausible as the IPCC's existing four scenario families.

Irreversible changes in the climate system

B1. The ongoing and well understood rise in temperature is likely, at some point, to lead to a range of large scale and irreversible impacts that would prove highly destabilising to the functioning of global human and biological systems. Examples of such impacts include, the melting of the Greenland and Antarctic ice sheets, changes in circulation in the Atlantic and dieback of Amazon and boreal forests.

B2. The timing and detailed implications of such 'tipping points' is, and will likely remain, poorly understood. What is however clear, is that the risk of such events rises with rising temperature and that, individually or collectively, such impacts may prove beyond the normal processes and rates of human or natural adaptation.

Impacts on international development

Many communities are already mal-adapted to the existing natural variability in weather systems, whether in relation to floods, storms, droughts, heatwaves or wildfires. The severe climate impacts of high emission futures needs to be overlaid on top of these vulnerabilities, with communities *struggling to meet the food, water and resource demands of rapidly rising populations and changing demographics. Such potentially catastrophic conditions will be exacerbated by highly inequitable access to the resources and capacities necessary to adapt.*

C1. In many areas and for potentially prolonged periods a combination of high temperatures, and humidity will limit the ability of humans to engage in demanding manual activities. Under high emission scenarios, and in the absence of major changes in working practices, labour productivity will reduce as temperatures rise and heat stress becomes an increasingly serious health issue. As women do much of the agricultural labour in poorer communities they will suffer unequally from heat stress.

C2. At lower temperature rises the increased concentration of carbon dioxide in the atmosphere may offset some of the reductions in yields from changes in climate and weather patterns. However in high emission futures with a 4°C mean temperature rise (and 5.5°C on land), the impacts on agriculture are set to be much more severe, with, for example the African continent having few, if any, crop analogues. According to the UK's Met Office maize and wheat yields reduce by up to 40% at low latitudes, with "30% decrease" in rice yields across China, India, Bangladesh and Indonesia.

C3. There is high confidence of extensive losses in biodiversity, with stark implications for those 'ecosystem services' on which society remains dependent. For instance, a combination of high seawater temperatures, ocean acidification and increasing pressures from fishing will escalate coral reef mortality, reducing fishery yields and coastal resilience.

Contents

Introduction

1. This research briefing gathers evidence on the likely impacts of climate change if the global energy system continues on a fossil fuel dominated pathway. It explores the viability and potential impacts of greenhouse gas emissions, specifically energy related carbon dioxide, at rates in excess of those captured within the "Representative Concentration Pathway 8.5" (RCP8.5). The four RCP families provide twenty-first century emission pathways and are used widely as inputs to climate models and policy analysis. As such they explicitly or implicitly frame virtually all current discussion on climate change. The pathway with the highest level of carbon emissions and hence temperature-related impacts is RCP8.5, which, although derived through a different process, is very similar to the IPCC's previous higher-end emission scenario, A1FI. Consequently, the IPCC process has and continues to be informed by a particular view as to the ceiling of emissions envisaged for the century.

2. The briefing that follows is broadly divided into three parts. The first considers emissions scenarios of fossil intensive development, how they relate to recent trends in consumption and estimates of remaining fossil fuel resources. The second section considers the likely impact of these emissions in terms of the extent of climate change and the possibility of irreversible changes in the climate system. Finally, the third section examines the consequences for poor and vulnerable communities in developing countries.

3. This report offers an overview of recent research in the academic and climate policy literature. It does not provide any new empirical evidence although additional calculations have been performed in some circumstances to allow comparison between studies.

Carbon emissions from fossil fuel intensive development; a plausible future.

4. Climate change is the result of the accumulation of greenhouse gases in the atmosphere, most significantly carbon dioxide (CO_2) from the combustion of fossil fuels. The atmospheric carbon dioxide concentration is currently at a level that has not been seen for at least 800,000 years and is rising at exponential rates due to human activity (IPCC 2013).

5. Despite the recent and unprecedented global economic slow-down actual emissions have continued to track slightly above the highest level of emissions envisioned in the scenarios used for international research and policy. In light of this there is merit in considering an emission pathway that reflects the possibility that emissions may well exceed RCP8.5. Such a pathway is reliant on three principal conditions: (i) there are sufficient 'affordable' fossil fuels; (ii) mean global economic growth continues at rates that demand increasing use of fossil fuels; and (iii) there are weak controls on emissions such that fossil-fuel domination of the energy mix remains unchallenged. The following section reviews each of these conditions in turn.

(i) Are there sufficient and affordable fossil fuels for emissions to exceed RCP8.5?

6. Determining whether emissions from fossil fuels could exceed RCP8.5 depends fundamentally on whether enough fossil fuels could be combusted, and this in turn depends on the level of geological *resources* and the proportion of these that are economically recoverable, i.e. the fossil fuel *reserves*, (assuming technical recoverability is solely or primarily a function of price).

7. In RCP8.5, primary energy demand increases three-fold by 2100, with most of this demand met by hydrocarbons. Coal supplies about half of the primary energy use, increasing in absolute terms by a factor of ten by the end of the century, relative to 2000. Coal-based liquids and 'clean coal' increasingly become part of the fuel mix (Riahi et al., 2011, p.44). This requirement for coal has

caused some to question the plausibility of previous IPCC climate scenarios on the basis of historical coal production trends and implied *reserves* (Rutledge 2011). Other authors argue that estimates of US coal reserves, as an example, are overstated and need to better account for economic influences (Grubert 2012, Milici et al 2013). However, multiple studies argue that there remains sufficient carbon emissions implicit within the range of current *resource* estimates (Rogner et al 2012) to exceed the emissions load of RCP8.5 (Riahi et al 2011, McCollum et al 2013).

8. Whilst the final level of oil consumption is similar to that in 2000, "large amounts of unconventional hydrocarbon resources well beyond presently extractable reserves" are required to fulfil demand throughout the century (Riahi et al., 2011, p.54). For comparison, the International Energy Agency considers "business as usual" fossil fuel trends in their Current Policies Scenario (IEA 2010). In absolute terms, the use of fossil fuels increases from around 12.3 Gtoe in 2008 to around 18 Gtoe in 2035, with coal displacing oil as the dominant fuel by a narrow margin. Geographically, demand for fossil fuels grows by more than 80% in non-OECD countries by 2035, while slightly decreasing in the OECD.

9. As with RCP8.5, the IEA's Current Policies Scenario significantly draws on unconventional oil resources, with their production increasing by a factor of five between 2009 and 2035, albeit from a low base. The production of natural gas liquids nearly doubles over the same period. This rapid growth is attributed to *"higher oil prices stimulat[ing] more investment in developing those higher-cost resources"* (IEA, 2010, p.118). The IEA report does not analyse other unconventional fossil fuels in detail within the Current Policies Scenario.

10. In terms of carbon dioxide emissions, the climate is largely ambivalent to the type of fossil fuel or mode of extraction. Consequently, all that matters is the quantity of coal, oil or gas considered economically recoverable, regardless of whether it is designated as conventional or unconventional. In light of new techniques for extracting fossil fuels, developed over the past two decades, there is now increased scope for the extraction of what were previously classified as 'unconventional' resources. In effect, there is now a much greater proportion of *resources* that can be converted into *reserves*.

11. From an emissions perspective, the rapid, successful and growing development of unconventional fossil fuels both adds to the current emissions burden and ultimately increases the uncertainty as to the quantity of economically recoverable fossil fuels available. Technical and economic developments that increase the proportion of resources that can be translated into reserves serve to increases the likelihood of there being sufficient fossil fuel reserves to exceed those assumed in RCP8.5.

12. The history of the post-war world is littered with concerns about the price of crude oil prompting an economic crisis. However, and despite relatively short-lived oil price shocks, global society has thus far proved relatively inelastic to the price of fossil fuels. In the 1970s $30/barrel was considered prohibitive, yet prices of up to $150/barrel have had limited impact in quenching absolute demand. Moreover, energy prices as a whole have increased substantially to levels previously thought unaffordable and destabilising, yet outside of issues of localised fuel poverty, global energy consumption has continued to rise rapidly. Today, across the EU car fuel is typically over $350/barrel[1], yet even during a time of major economic recession, vehicle-kilometres travelled have stabilised rather than reduced. Similar arguments can be made for gas for heating in the UK and elsewhere. Consequently, it is reasonable to assume that if the global community returns to pre-downturn rates of economic growth, barrel prices for fossil fuels could be sustained at levels well in

[1] Based on the simplistic assumption that a barrel of sweet crude primarily yields diesel/petrol. In reality the proportion of automotive fuel will be much lower, perhaps 50-70% (and lower for sour crude). The other products range from distillate fuel oil and kerosene to heavy fuel oil and bitumen.

excess of $150, with very significant incentives for further development and increased conversion of resources into reserves.

13. Given the ability of contemporary society to absorb high energy prices, combined with the prospect of new technologies for extracting fossil fuels, there is certainly value in considering energy scenarios with emissions in excess of those in RCP8.5. A recent study constructing plausible variations of the IPCC A1FI scenario (the predecessor to RCP 8.5) suggests that global emissions may be between two and four times higher than the levels within A1FI by 2100 with just minor variations in population growth, primary energy demand and fuel mix parameters (Sanderson et al., 2011). However, in doing this it is important to recognise that there are some experts who consider that even the scale of fossil fuels underpinning RCP8.5/A1FI is unrealistic. Nevertheless, others take a different view, and it is this that informs the remainder of this briefing note.

(ii) Could global economic growth demand increasing rates of fossil fuels use?

14. The growth in carbon dioxide (CO_2) emissions between 2000 and 2008 was over 3% p.a.[2], a rate considerably higher than during the latter decades of the twentieth century (~1% p.a. for 1990-2000). A significant driver of this recent and accelerated growth was and remains emissions released from developing countries (particularly China); i.e. nations without emissions caps which are referred to in climate policy terms as "non-Annex 1 nations". In aggregate, emissions from non-Annex 1 overtook those from Annex 1 (wealthier countries with emissions targets), in 2006[3] and have continued at relatively high rates throughout much of the economic downturn evident across many of the more industrialised nations.

15. Whilst emissions in Annex 1 nations have begun to stabilise, if not exhibit a slight decline[4], this has and is very likely to continue to be more than offset by rising emissions from increasing numbers of non-Annex 1 nations. To date the processes of globalisation and of rapid increases in indigenous consumption have remained relatively confined to a sizeable and growing proportion of China's population along with smaller (though increasing) proportions of those across other non-Annex 1 nations. Consequently, in a 'stable' world characterised by trade and comparative advantage it is not unreasonable to envision the prosperity successes of China being mirrored across other non-Annex 1 nations. In such a world, global economic growth may well exceed historical precedents. If fuelled primarily by hydrocarbons, such growth will likely be accompanied with rates of emission increase in excess of those witnessed in the earlier years of the new millennium.

(iii) Could climate change legislation remain weak?

16. The IPCC was established in 1988, with its first report published in 1990. In the subsequent quarter of a century there have been repeated attempts to develop a global framework for cutting emissions in line with the international community's commitment to "stay below" the 2°C characterisation of dangerous climate change. Despite the annual rounds of high-level negotiations the international community has thus far failed to even curtail the increase in the rate of emissions growth. Still more concerning, at a domestic national level, no country has successfully reduced the carbon intensity of their typical citizens' lifestyles (i.e. on a consumption basis) through judicious mitigation policy.

17. The next major round of negotiations is planned for Paris in December 2015 (COP21), where an agreement is to be fleshed out for establishing binding emission targets for post 2020. Whilst it is to

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[2] Calculated from CO2 emissions presented in http://www.globalcarbonatlas.org/?q=emissions for the years 2000 and 2008.

[3] Ibid. Note, the Carbon Atlas uses the Annex B nomenclature; which for this purpose is an adequate proxy for Annex 1.

[4] Though consumption-based emissions (as opposed to territorial production-based) of many Annex 1 nations have not witnessed such a decline. In the UK, for example, consumer based emissions are today similar to their 1990 level, despite territorial emissions being ~18% lower. Prior to the post-2008 economic downturn, consumption-based emissions were ~11% higher than in 1990. (Ibid)

be hoped that COP21 will deliver a meaningful and effective framework, experience suggests there is a reasonable probability that nothing significant will be forthcoming. Consequently, it is reasonable to assess the potential for emissions growth under the assumption of there continuing to be no meaningful carbon constraints (i.e. the ongoing failure of international agreements and their national implementation).

Impact of fossil intensive scenarios on the climate

Expected global changes

18. Projections of future climate are uncertain due to our incomplete understanding of the climate system, inherent natural variability and the range in possible future emissions. The IPCC considers the impact of man-made greenhouse gas emissions by using a consistent set of emissions scenarios e.g. RCP8.5, in multiple climate models with different designs and complexity. This ensemble approach offers a range of expectations about the future climate and allows a greater understanding of climate variability, the models themselves and the processes they represent.

19. The latest iteration of this process, the CMIP5 project, considers both near-term (2016 to 2035) climate response and long term changes (end of the 21st Century and beyond). Whilst in the near term, climate models show limited sensitivity to the forcing by anthropogenic greenhouse gases, in the long term there are substantial differences according to the assumptions made about future emissions.

20. Annual greenhouse gas emissions in RCP 8.5 are more than twice the 2000 level in 2050 and three times higher by the end of the century; this level of emissions is higher than in typical baseline scenarios (Riahi et al., 2011, p.48). The RCP 8.5 cumulative budget is 5193–7010 GtCO2, between 2012 and 2100, leading to an atmospheric CO_2 concentration of approximately 1000 ppmv (IPCC, 2014b, Chapter 6, p.24).

21. Accordingly, a global mean surface temperature change of 4.3°C above the pre-industrial era (with a likely range of 3.2 to 5.4°C) would be expected by the end of the 21st century were global emissions to follow the RCP 8.5 trajectory. The emissions budget associated with a 66% chance of staying below 2°C is exceeded in RCP 8.5 by 2046 (Sanford et al 2014).

22. This is comparable to the IEA's Current Policies Scenario, with an associated CO_2 atmospheric concentration of around 1,000 ppm by around 2100 and "a long-term… temperature rise in excess of 6°C." (IEA, 2010, pp.383-384). The 'long-term' is not defined in the IEA report, but it is likely to be the equilibrium warming rather than a transient temperature at the end of the 21st century.

23. Both the RCP8.5 scenario and the IEA's Current Policies Scenario exceed 4°C by 2100 relative to 1850–1900 with 53–78% likelihood. The IPCC gives a range 3.7 ± 0.7°C in 2081–2100 (IPCC, 2013, Table 12.2 on p.1055). According to the IPCC, a 4°C median temperature increase above 1980–1999 in the RCP8.5 scenario occurs around 2090–2099 (IPCC, 2013, Fig. 12.40 p.1100).

24. Climate models coupled with ice sheet and glacier dynamic process models may be used to project global mean sea level rise. Under RCP 8.5, the current likely expectation is of a 0.52m to 0.98m rise (relative to 1986-2005) by 2100 with medium confidence in these values (IPCC, 2013, p98). Unlike mean surface temperature rise, sea level rise depends not only on cumulative emissions but also the shape of the pathway due to the dynamics of the underlying processes. Trajectories with lower emissions in the near term have a lesser extent of sea level rise for the same total.

Instabilities and feedbacks in the climate system

25. It has been suggested that a number of parts of the climate system may not respond in a linear way to global mean temperature rise and may instead change substantially past a certain threshold,

often referred to as "tipping points" (Lenton et al 2008). Examples include tropical and boreal forest dieback; disappearance of Arctic summer sea ice as well as the Greenland and Antarctic ice sheets; alteration of monsoon rains and the thawing and release of methane from permafrost and subsea clathrates.[5] Some such changes may only be reversible on the scale of centuries although others may reverse on a decadal scale if anthropogenic forcing is removed. They may also have further influence over the climate, producing positive or negative feedbacks in the local or global climate.

26. In general, the IPCC AR5 report cites low confidence in scientific knowledge of the particular probabilities of such changes, but does provide some information on the potential consequences (Collins et al 2013). It is difficult to make predictions of major biophysical and geological changes over the short timescales, relative to natural systems, that society is concerned with. Historical reconstructions may give indications of possible processes and their extent but not detail on dynamics and future expectations. Timescales for cause and effect need to be considered carefully when comparing studies; the processes concerned may occur over centennial or millennial scales following small but persistent alterations in atmospheric GHG concentrations. As a result, studies to investigate these processes are not typically aligned to near term emissions scenarios such as RCP 8.5.

27. Aspects of permafrost thawing have been found to be inconsistent across climate models, due to insufficient understanding of soil carbon processes. Some studies have indicated that carbon stored in permafrost is being remobilised at present, however, work to upscale from sites to regions is at an early stage (Kuhry et al 2010). Whilst permafrost is expected to become a net emitter under the RCP scenarios, and would likely be irreversible on human timescales, it is not considered to be a potentially abrupt process by IPCC AR5 although confidence on this is low.

28. There is greater confidence in understanding the response of methane clathrates; climate change is very likely to increase the emissions of methane from terrestrial and subsea sources. Research into the rates of related physical and biological processes affecting subsea clathrates suggests it is very unlikely that there will be a catastrophic release of methane from their destabilisation within the 21st century, however, this source of emissions may lead to an irreversible positive feedback over millennial timescales (Brooke et al 2008).

29. There is high confidence that the Greenland ice sheet will reduce in volume and area in a warmer climate, and whilst unlikely to cross a threshold within the 21st century, decreases are likely to be irreversible over millennial timescales under high emissions scenarios (Collins et al 2013, 12.5.5.3). There is a medium degree of confidence that the threshold for near complete loss of the Greenland ice sheet is more than 2°C but less than 4°C mean temperature rise above preindustrial times. Because of the ice sheet's influence over its regional climate the reversibility of any ice loss is not only to do with global temperature change. Long term model runs suggest that even if atmospheric GHG concentrations return to pre-industrial levels, if an ice sheet volume loss threshold of around 10% to 20% occurs during a strong warming period, 20% loss is irreversible (Ridley et al 2010). This 'point of no return' could be reached within a few hundred years with an associated sea level rise of at least 1.3m. If elevated atmospheric GHG concentrations are maintained and greater ice is lost then an alternative stable state with much lower ice sheet volume and 5m higher sea level is observed.

30. The Antarctic ice sheet is the largest potential contributor to sea level rise, with the volume of water stored in the West Antarctic Ice Sheet alone sufficient to raise global sea level by approximately 4.3m. Antarctica's quantity of ice depends substantially upon the rates of solid ice loss to the sea and

[5] Methane clathrates, also known as methane hydrates, are crystal structures combining ice and methane. They are found predominantly in ocean sediments, where they are stabilised by high pressures, but also within permafrost and some sedimentary rocks.

accumulation from snowfall, both affected by climate change. Rates of snowfall are low on Antarctica and any loss of ice in the near term would likely be irreversible on a multi-centennial time scale (Kirtman et al 2013, 13.4.4.3). A warmer atmosphere is expected to lead to greater snowfall as more moisture is carried polewards, however current evidence suggests that the increase in snowfall is outweighed by outflow to sea. Recent observations and numerical simulations of ice sheet dynamics, that are not coupled to climate models, have suggested that the collapse of one coastal system, the West Antarctic Ice Sheet, may already be under way (Joughin et al 2014, Rignot et al 2014). The Wilkes Basin in East Antarctica has also been shown to be vulnerable to positive feedbacks leading to 3-4m sea level rise in the long term once an initial threshold is passed (Mengel and Levermann 2014). This is estimated to be a centennial rather than millennial scale process although there is large uncertainty over the precise timescale over which the collapse would complete.

31. A threshold in precipitation volume and dry season duration may exist in tropical forests, notably Amazonia. However, observations of increases in Amazonian dry season length cannot currently be attributed to climate change as these processes are not integrated within the models assessed by the IPCC (Fu et al 2013). As with the response of boreal forests, this potential change is highly uncertain and the IPCC has low confidence in projections of the dieback of large areas due to climate change.

32. In their review for the Government Office for Science, New et al (2011) conclude that only a small number of putative tipping points are may be reached under the high end of RCP 8.5 projections by 2060, even if they may ultimately be exceed on longer timescales. Of these, the loss of tropical coral reef ecosystems may be the most significant to developing countries as it would have consequences both for coastal defence and food production. IPCC AR5 WG1 does not refer to coral reefs as significant participants in the global climate system as the biophysical consequences are localised.

33. In summary, there exists the possibility of non-linear and irreversible responses in a number of biophysical systems but confidence in determining temperature thresholds is low. However, some changes, such as the loss of the Greenland Ice Sheet and West Antarctic Ice Sheet are likely to occur over long timescales with modest but persistent increases in anthropogenic climate forcing, with substantial influence on sea level rise and hence coastal inundation.

Regional effects of climate change

34. Although global surface temperature rise is a useful metric in climate science it is not directly experienced by communities, rather we face diverse and specific variations in daily, extreme and seasonal patterns of temperature and precipitation. There are uncertainties in downscaling specific climate impacts to a regional level and the IPCC describes certain types of 'climatic implications' with careful statements of probability and confidence.

35. Annex 1 of the IPCC AR5 WG2 (2014a) report includes an Atlas of Global and Regional Climate Projections with maps of regional climate data. However, these changes in temperature and precipitation are shown only for the RCP 4.5 scenario. Numerical descriptions are provided in chapter 22 and we illustrate two regions below. New et al (2011) infer regional climate impacts for RCP 8.5 in 2060 by cross referring global mean temperature rises in RCP 8.5 simulations to the CMIP3 archive (p8). They suggest that regional changes in temperature and precipitation are likely to be amplified for higher global temperatures.

36. Example regional impacts are detailed below for the RCP8.5 scenario (i.e. for approximately a 4°C temperature rise by 2100) including regional temperature rises, rainfall and extreme weather events. IPCC AR5 WG2 reports that average temperatures are projected to increase faster in Africa than globally (IPCC 2014a). Five African regions are very likely to see 3–6°C temperature increases by 2100, relative to 1986–2005. (IPCC, 2014a, Chapter 22, pp.8-9) A higher degree of uncertainty and variation is associated with projections of rainfall than of temperature. The average annual rainfall is

likely to decrease in central and eastern Africa after 2050; this decrease is very likely for northern and southern Africa. (IPCC, 2014a, Chapter 22, p.10) Reduced rainfall may result in more heat waves and droughts. Southwest Africa in particular is at a high risk of severe droughts. At another extreme, heavy rainfall may become more frequent, resulting in floods. (IPCC, 2014a, Chapter 22, p.12)

37. Average temperatures over much of Asia will cross the 2°C increase (above ~1999) around 2050. Greater than 3°C temperature rises are projected in South and Southeast Asia nearer the end of the century, with more than 6°C at high latitudes. (IPCC, 2014a, Chapter 24, p.6) Increased rainfall is very likely over high latitudes by mid-century and over East and South Asia by 2100. There are large variations in projections of extreme whether events by region in Asia. The IPCC AR5 suggests extreme rainfall in relation to the monsoon is very likely in East, South and Southeast Asia, but a particular scenario (e.g. RCP8.5) is not specified. (IPCC, 2014a, Chapter 24, p.7).

Impacts on International Development

38. Natural variability in weather systems leads to significant negative consequences for many populations at present, through flood and wind damage, droughts, heatwaves and wildfires. The additional impact of anthropogenic climate change will lead to diverse consequences that mediated by an uneven distribution of vulnerability, exposure and non-climate stresses often affecting poor communities.

39. The Technical Summary of IPCC AR5 WG2 Box TS6 addresses the question of large temperature increases, with reference to 4°C warming and RCP 8.5. Headline conclusions directly relevant to international development include:

    a. A combination of high temperature and high humidity in some areas of the world will limit growing food and working outdoors by 2100.
    b. Widespread coral reef mortality is expected with consequent impacts on the communities that presently benefit from them.
    c. There is high confidence that the ecosystem changes anticipated would result in extensive loss of biodiversity and ecosystem services to society.
    d. Large decreases crop yields, increased exposure to water stress and flooding (rain caused and coastal), would be significant and potentially compounding impacts on global society and economic development.

40. The stress placed on workers by high temperature and humidity already reduce global labour capacity by 10% of its maximum in peak months, however, under RCP 8.5 this may reduce by 37% by 2100 (Dunne et al 2013). In the Sahel and some parts of the Indian sub-continent it may considerably inhibit farming; for instance Patricola and Cook (2010) estimate that people in the Sahel region in may experience up to 160 days per year with a likely risk of heat stroke by 2100 under the A2 scenario (lower than RCP 8.5). As women do much of the agricultural labour in poorer communities they will suffer unequally from heat stress.

41. In the past several decades, there is evidence that wheat and maize farming has been affected by climate change, more so than rice and soybean. Increasing extreme daytime temperatures during the growing season around 30°C has been shown to have negative impacts on yield, whilst elevated CO_2 concentrations have a stimulating effect in some circumstances (Field et al 2014, p10).

42. Agricultural impacts studies often restrict the timeframe of their analysis to 2030 or 2050, at which point statistically significant divergence between emissions scenarios is limited, although a number of studies are identified (New et al 2011). Determining impacts is also complicated by the necessity of assumptions about farmers' behaviour and response to change such as the adoption of new crop varieties and irrigation practices, and the impact of extreme events (IPCC 2014a, 7.2.1).

43. Burke et al. (2009) consider climate change under the A1B scenario, with lower rates of change of emissions and impacts than RCP8.5, relating the anticipated future regional climates to 2075 to historical climate data and the agricultural systems for maize, millet and sorghum. Under these circumstances changes in growing season temperature are much more substantial than changes in precipitation. They find that for the majority African countries, farming communities will be dealing with temperatures beyond their own and their countrymen's experience over half their crop area by 2050. They identify a set of predominantly Sahelian countries that in future are not expected to have existing crop and climate analogues anywhere else on the continent.

44. Within the range of what may be experienced under RCP 8.5 by the end of the century, Thornton et al (2011) examine a scenario of 5°C mean warming over pre-industrial using the IPCC AR4 scenarios and data sets. Downscaling the impacts to sub-saharan Africa, they find mean yield reductions in maize and beans of 24% and 71% respectively. They conclude that adaptive practices will be key but that the substantial differences between climates experienced could overwhelm hundreds of millions of small scale farmers, many of who are already very vulnerable.

45. Generally, distinct thresholds for agricultural system changes are not well characterised given the concatenation of uncertainties. However, Schlenker and Roberts' (2009) study of US maize, soybean and cotton demonstrates sharp changes in crop-yield above crop-specific mean temperature thresholds. Their wide statistical analyses suggest there is limited historical evidence for adaptation and that yields may drop 63-82% by 2100 under their highest emissions scenario if cultivated areas and farming practices remain static.

46. Whilst the potential for substantial changes in agriculture and water systems leading to mass migration is significant, the numbers of people at risk of severe impacts is difficult to quantify due to their geographic specificity, adaptive responses and the likelihood of interactions between impacts and policies. The UK Government Foresight report on the topic argues that producing deterministic quantitative "...global estimates of 'environmental migrants' is methodologically unsound…". However, looking at the climate related drivers of migration in isolation, New et al (2011) identify 44 countries totalling 400 million people who may face severe reductions (>20%) in both water and food by 2060 under high climate change scenario with 1.28 billion people in 50 further countries may suffer moderate (5-20%) decreases of food and water.

47. By 2100 under warming shows that the bulk of the world's population living in large urban agglomerations will be exposed to a minimum 2.5 degree temperature rise and peak seasonal increases could be higher. Spatial patterns of economic development also interact with vulnerability to climate impacts. Recent urbanisation in low and middle income countries combined with growing populations in large cities leave many communities living in informal settlements on land that is more exposed to extreme weather (IPCC 2014b 8.2.3). Such ongoing trends may in future exacerbate the impacts of climate change.

48. Range shifting in natural resources such as fisheries may have significant uneven consequences. 90% of people globally engaged in fishing are in employed in small scale fisheries, many of these in poorer countries where this valuable protein source contributes substantially to food security. Whilst fisheries yields in some high latitude regions may increase by 30-70% by 2055 there may be a drop of 40-60% at tropical latitudes for a warming of 2°C. Coral reefs provide food and other resources to approximately 500 million people and there is high confidence that these fish and invertebrate species will reduce in availability (IPCC 2014a 7.2.1.2). In all of the IPCC scenarios greater CO_2 emissions than RCP 2.6, ocean acidification will impact the formation and maintenance of coral reefs although quantification is uncertain due to limited research in this area (IPCC 2014a Box CC-OA).

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