WORLD ECONOMIC AND SOCIAL SURVEY 2016:

Climate change resilience — an opportunity for reducing inequalities

BACKGROUND PAPER

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Identifying opportunities in a changing climate: Research priorities for reducing vulnerability, poverty and inequality

*By: Luis Carlos Jemio and Lykke E. Andersen **

Summary:

At this point in history, inequality both between and within countries is staggering, and climate change, extreme climate events, and other adverse shocks threaten to further aggravate this inequality, as poorer households tend to be more vulnerable and suffer more from adverse shocks and stresses than richer households. To counteract this tendency, it is important that global and national climate change policies are designed specifically to reduce the vulnerability of the poor and decrease inequality.

In this paper we discuss what kind of research and tools can help inform the design of smart policies that simultaneously reduce vulnerability, poverty and inequality. We argue that such tools need to: 1) explicitly address inequality; 2) take into account climate variability, rather than just climate change; 3) target general vulnerability, rather than very specific vulnerabilities; 4) address immediate problems, rather than distant threats; 5) be simple to implement, so as to be feasible for those who need it most; and 6) involve low or moderate levels of uncertainty.

We find that disaster risk management systems and resilient crop development efforts are very worthwhile efforts as they can be targeted to address the current vulnerabilities of poor people, while also helping to reduce future risks from adverse climate events. In contrast, integrated assessment models are designed to assess problems in the distant future and are thus not very helpful to inform current adaptation policies and alleviate current problems of vulnerability and inequality. In addition they involve so much uncertainty that they cannot even be used to help design very long term infrastructure (such as hydroelectric power plants).

** The authors are affiliated with the Institute for Advanced Development Studies in La Paz, Bolivia. Views and opinions expressed are those of the author and do not necessarily reflect those of the United Nations.*

1. Introduction

Worldwide inequality is already staggering, with people in the richest countries easily earning more than a hundred times more than people in the poorest countries. And apart from tremendous between-country inequality, there is also vast and increasing inequality within countries. According to United Nations, on average—and taking into account population size—income inequality increased by 11 per cent in developing countries between 1990 and 2010[1].

Climate change and extreme climate events threatens to further aggravate existing inequalities, as poor people and poor countries are widely believed to be the ones that will suffer most from the effects of both climate change and climate variability.

There is an urgent need to address both problems, and interventions can potentially be more effective if the two problems are considered jointly. The purpose of this paper is to identify which kind of research would be most useful for jointly addressing vulnerability, poverty and inequality.

The remainder of the paper is organized as follows. Section 2 discusses the differences between climate change and climate variability, and argues that it is not the slow changes in the average weather (climate change) which pose the biggest problems, but rather extreme climate events caused by unavoidable, and perhaps increasing, climate variability. Section 3 discusses the different types of extreme climate events, while Section 4 shows that tropical cyclones are the ones that cause the most material damage and kills the most people. Section 5 proceeds to analyze a number of analytical tools used in the climate change literature. Six different criteria are used to evaluate how useful each of the tools are to help formulate policies that simultaneously reduce vulnerability, poverty and inequality. Section 6 concludes.

2. Climate change versus climate variability

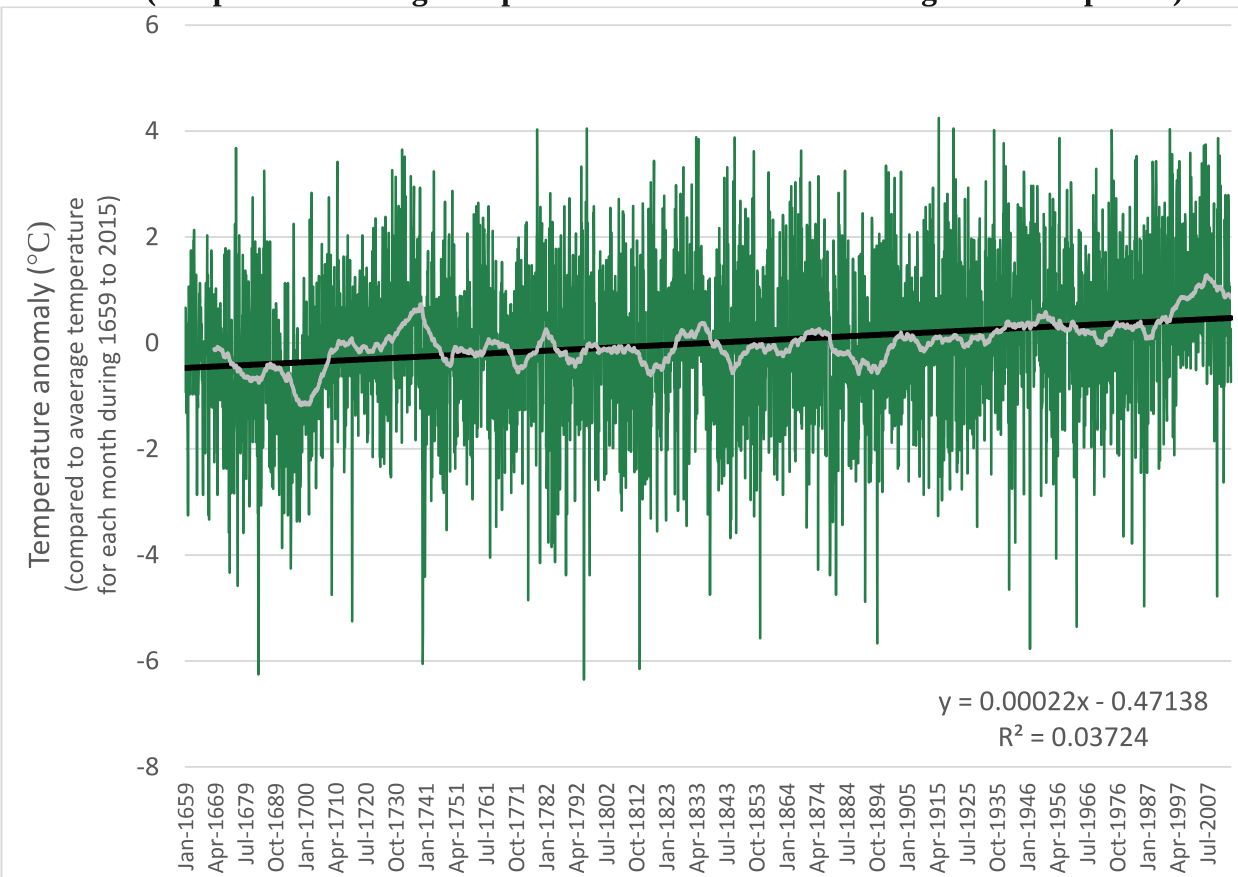
Robert A. Heinlein wrote "Climate is what you expect, weather is what you get", and this difference between climate and weather is of great importance when analysing vulnerability and resilience. Weather, by definition is a lot more volatile than climate, since climate is defined as the average weather over several (usually three) decades, and thus by definition excludes natural year-to-year variability.

The difference between climate change and climate variability can be illustrated by plotting any climate related variable over time, and comparing the measured values with the trend line. For example, Figure 1 plots the monthly temperature anomaly in Central England during the last 357

[1] See http://www.un.org/sustainabledevelopment/inequality/.

years (the longest temperature series that exists in the World). There is a significant upward trend, which reflects climate change, but there is also substantial variation around that trend.

Figure 1: Monthly temperature anomalies in Central England, Jan. 1659 – Sep. 2015 (compared to average temperature for each month during the whole period)



Source: Authors' elaboration based on data from the MetOffice (http://www.metoffice.gov.uk/hadobs/hadcet/data/download.html)

Note: The thick black line is the linear trend line, while the undulating grey curve is the 120 month moving average.

The linear trend line indicates climate change in the order of +0.00022°C per month (corresponding to 0.26°C per century). In this series, about 3.7% of the variation in temperatures over the last 357 years is explained by climate change, while the remaining 96.3% is explained by climate variability (see the R^2 of the trend line in the graph). This simple fact highlights the utmost importance of addressing not only climate change, but also current climate variability. Even if we managed to stop climate change (that is, keep the trend line horizontal), we would only solve about 4% of our climate problems. The remaining 96% can only be dealt with through adaptation measures that make us more resilient to current and future climate variability.

While we can statistically distinguish between climate change and climate variability, we cannot distinguish between anthropogenic climate change and natural climate change. But the distinction is irrelevant when analysing vulnerability and resilience. When disaster hits, it doesn't really matter whether it was anthropogenic climate change, natural climate change or natural climate variability that caused it. Indeed, for any particular event, it would be impossible to tell the three apart. What is clear from the Central England temperature series is that the region experienced rapid warming much before the industrial revolution. For example, average annual temperatures increased more than 2°C between 1695 and 1736, despite low atmospheric CO_2 concentrations. This implies that there are both natural and anthropogenic factors behind the observed temperature trends, and in this paper we will not attempt to distinguish between the two. We simply define all long term (several decades) changes as climate change, and all short term (from year-to-year) changes as climate variability.

Given the dominance of climate variability both now and for many decades into the future, it is important not only to analyse the impacts of anthropogenic climate change, but also to analyse climate variability and extreme climate events. In the next sections we will analyse extreme climate events and assess which types tend to cause the most damage to whom. This kind of analysis is very important for addressing current vulnerabilities and inequities.

3. Extreme climate events

Extreme climate events can be grouped into the following five main categories:

- Extreme heat
- Extreme cold
- Extreme rainfall
- Extreme lack of rain
- Extreme winds

However, what is extreme in one place, may be perfectly normal in another place, so extreme events always have to be evaluated in the local context. Likewise, what may be perfectly normal for one time of the year, could be extreme for another time of the year, so extremes also have to be evaluated within a seasonal context.

Extreme events by definition do not happen very often. Engineers and city planners usually design infrastructure to withstand at least a 1-in-30 year events, but for critical structures (like a dam located upriver from a big city), they might even plan for a 1-in-1000 year flood. A 1-in-100 year event has a 1/100 = 1% probability of happening in any given year, and a return level of 100 years.

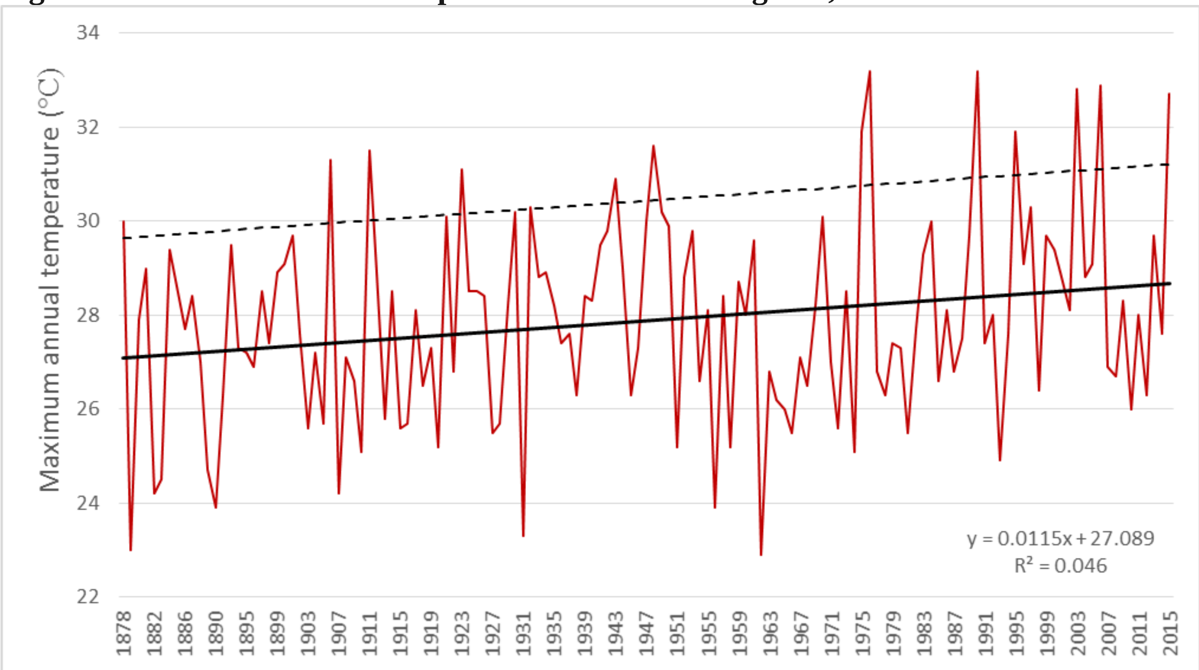
The National Oceanic and Atmospheric Administration (NOAA) in the United States defines extreme climate events as events that lie in the outermost 10 percent of the distribution for any particular place's history[2]. These events would thus have a 10% chance of happening in any given year, and a return level of 10 years.

3.1.Extreme heat

Extreme heat can cause problems for people, crops, livestock, nature and even infrastructure. One important, but not so obvious effect of heat, is that it can increase air contamination. During excessive heat episodes plants shut their stomata (pores on the leaves) in order to reduce water loss from evapotranspiration, but this reduces their ability to absorb and neutralize air pollutants, such as ozone (O_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) (Nowak et al., 2014). Power outages can also occur within areas experiencing heat waves due to the increased demand for electricity (i.e. air conditioning use).

Extreme heat is best measured by maximum daily temperature series. While Central England may not be the best example to illustrate extreme heat problems, it the longest and most complete series that we could find of maximum daily temperatures. Figure 2 shows the evolution of the highest temperature measured each year in the Central England record (from 1878 to 2015). The maximum annual temperature has been increasing at a rate of about 1.15°C per century, which is 29% faster than the rise in average annual temperatures during the same period (0.89°C per century).

Figure 2: Maximum annual temperature in Central England, 1878-2015



[2] http://www.ncdc.noaa.gov/climate-information/extreme-events.

Source: Authors' elaboration based on data from the MetOffice (http://www.metoffice.gov.uk/hadobs/hadcet/data/download.html).

Note: The red line shows the maximum annual temperature each year, the solid black line is the simple linear trend, and the dotted black line is the trend line plus 1.2 standard deviations, which in this particular series separates the 10% extreme high temperature values observed.

The dotted line in Figure 2 is the threshold that separates the 10% highest maximum annual temperatures in the series (14 out of the 137 year record). These would be the 14 years of extreme heat in Central England, according to NOAA's definition.

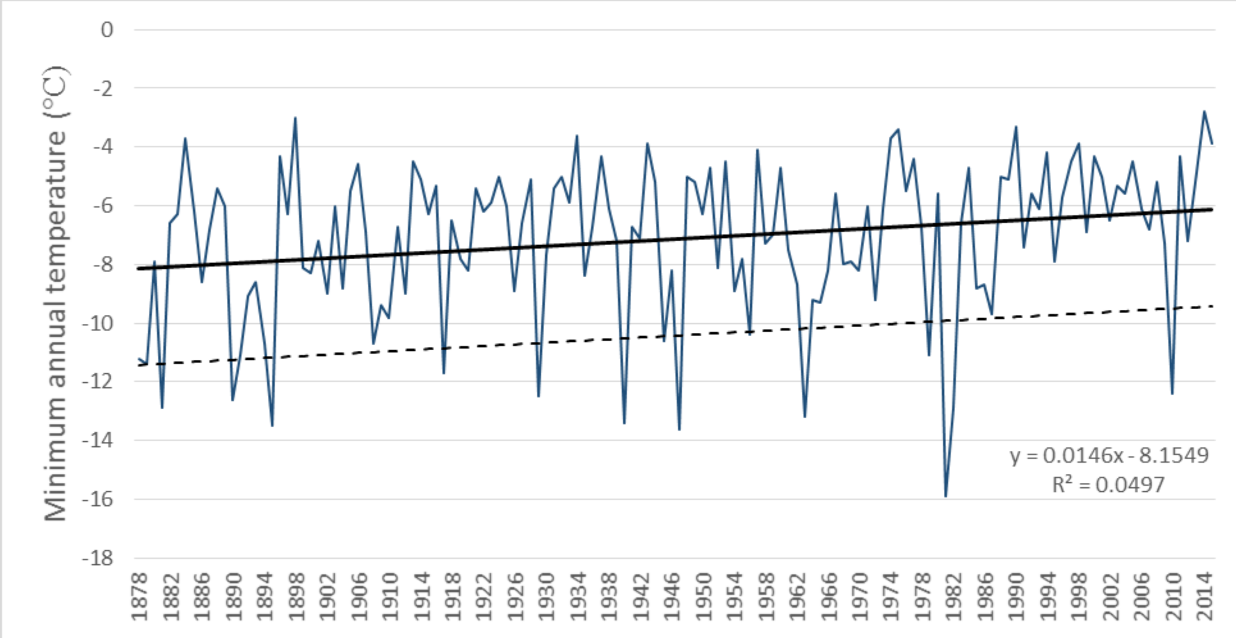
The years 1976 and 1990 tie for the heat record of 33.2°C, but the heat wave of 1976 was by far the most severe, as it lasted for 14 days with temperatures reaching above 29°C. In 1990 there were only three consecutive days above 29°C, and in 2015, it was just one hot day (the 1st of August) of 32.7°C, immediately followed by a rather cool day of only 21.8°C.

3.2.Extreme cold

Like record hot temperatures, extreme cold temperatures might also be of concern, as they can harm or kill people, animals, and plants, freeze and rupture water pipes, and cause traffic chaos and accidents.

Figure 3 shows the lowest temperature recorded each year in the Central England daily temperature record. The minimum temperature has been increasing at a rate of about 1.46°C per century, which is 64% faster than the increase in average temperatures over the same time period (0.89°C per century). The dotted line in the figure separates the 10% coldest minimum annual temperatures in the 137 year series. The all-time record minimum was observed in the winter of 1981/82, where temperatures dropped to -15.9°C on the 13th of December and then dipped to -12.9°C again in mid-January.

Figure 3: Minimum annual temperature in Central England, 1878-2015



Source: Authors' elaboration based on data from the MetOffice (http://www.metoffice.gov.uk/hadobs/hadcet/data/download.html).

Note: The blue line shows the minimum annual temperature each year, the solid black line is the simple linear trend, and the dotted black line is the trend line minus 1.25 standard deviations, which in this particular series separates the 10% extreme low temperature values observed.

With minimum temperatures increasing slightly faster than maximum temperatures, the Central England temperature record shows a slight tendency towards reduced climate variability. The variance of the first half of the total daily temperature series is 3587, while the variance of the second half is 3580.

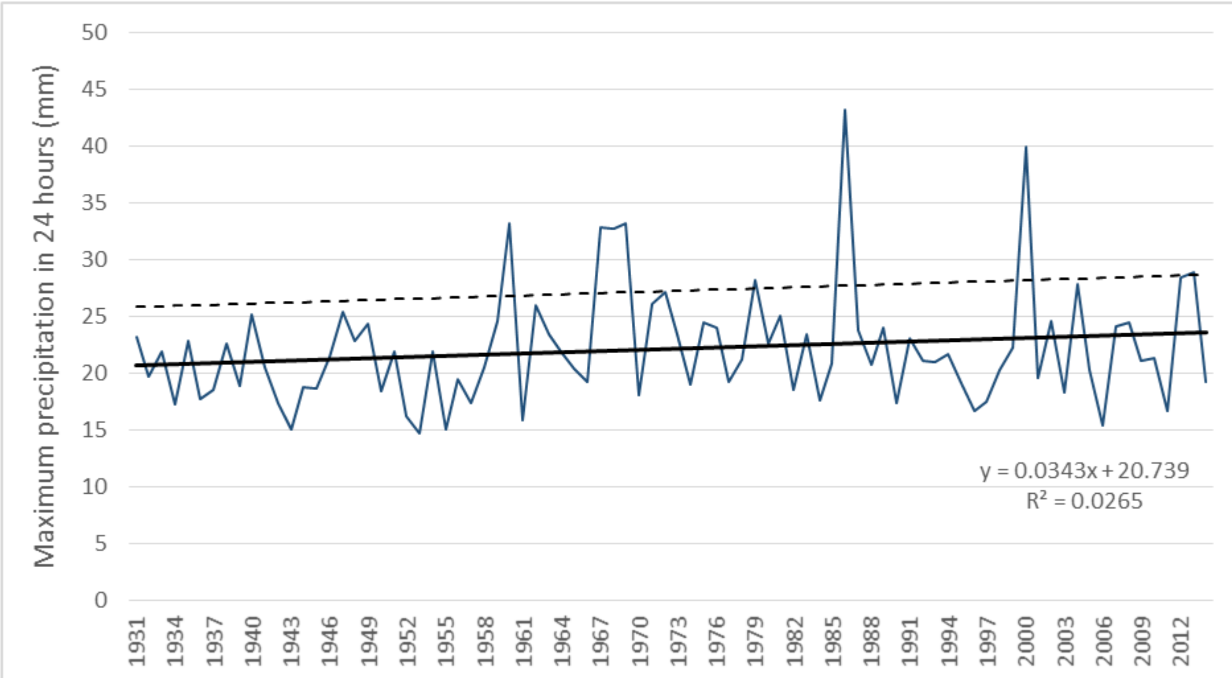
This is of course only one temperature record, and other places may show different patterns. One needs quite long and complete temperature series to analyse extreme events and changes in variability, and very few such records exist. This is why climate science relies so heavily on computer simulations instead of data.

3.3.Extreme rainfall

Extreme amounts of rainfall can cause extensive damage through flooding. To cause damage, substantial precipitation has to fall within a short time, usually a few hours or a few days. A commonly used indicator for extreme rainfall is the maximum amount of precipitation in 24 hours. Figure 4 shows that the maximum amount of rainfall in England and Wales has been increasing over the 84 years for which data is available.

The all-time record was for the 25th of August 1986 where 43 mm of rain fell in one day. There is a slight upward trend in maximum precipitation, suggesting increasing risk of flood damage in this region.

Figure 4: Maximum precipitation in 24 hours in England and Wales, 1931-2014



Source: Authors' elaboration based on data from the MetOffice http://www.metoffice.gov.uk/hadobs/hadukp/data/download.html). Formal reference: Alexander, L.V. and Jones, P.D. (2001) Updated precipitation series for the U.K. and discussion of recent extremes. Atmospheric Science Letters doi:10.1006/asle.2001.0025

Note: The blue line shows the maximum precipitation in 24 hours each year, the solid black line is the simple linear trend, and the dotted black line is the trend line plus 1 standard deviation, which in this particular series separates the 10% extreme high values observed.

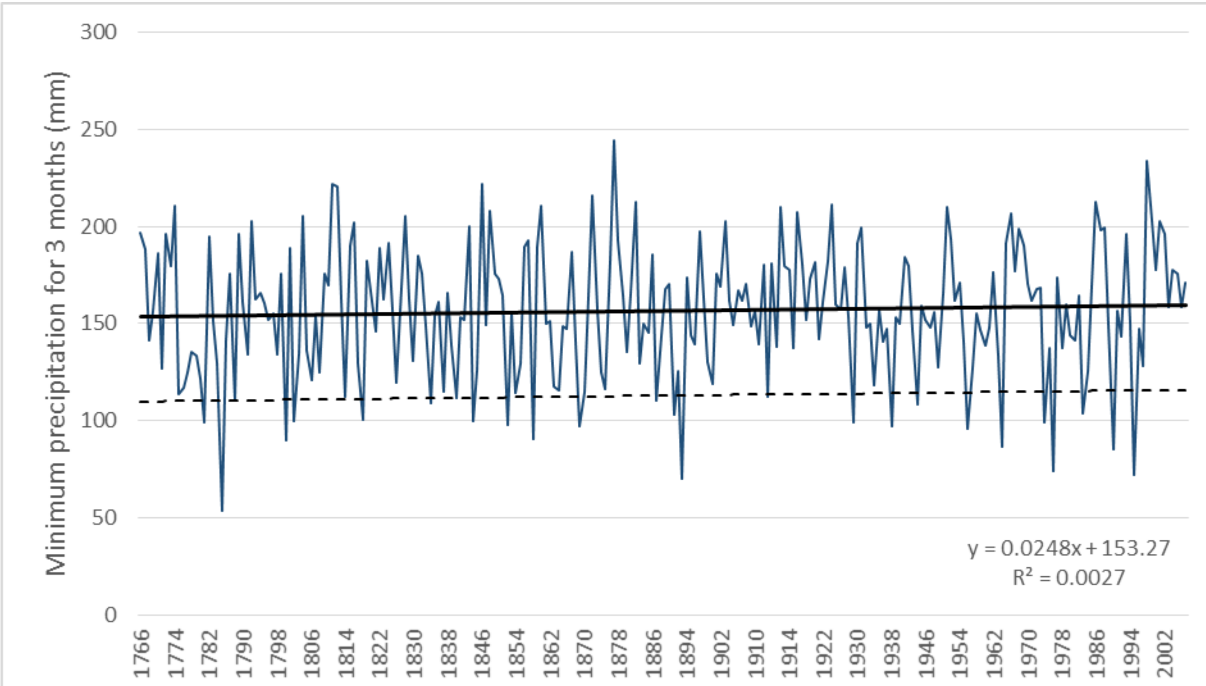
Again, this is just one series, and other places may show different trends, but this tendency is in accordance with climate theory. All General Circulation Models of the climate agree that there will be more precipitation in a warmer world, and they also agree that precipitation will tend to be concentrated in heavier precipitation events, because a warmer atmosphere can hold more water. It is therefore reasonable to expect and prepare for more heavy precipitation events everywhere.

3.4.Extreme lack of rain

Drought is one of the main worries related to climate change in all regions of the world (PEW Research Center, 2015), but it is not easy to measure and characterize drought events, as they depend not only on precipitation, but also on temperature, soil moisture, and stream flow. For farming purposes, quite detailed real-time monitoring is necessary, but for the purpose of establishing a rough trend in droughts, we can use standard precipitation data.

Figure 5 shows the minimum seasonal precipitation in England and Wales during the two and a half centuries from 1766 to 2007. There is a slight upward trend in minimum precipitation, suggesting less chance of drought, but extreme events (below the line that separates the 10% lowest observations) do not seem to have become less frequent. (A more thorough Extreme Value Analysis would have to be carried out to determine if there are any significant changes).

Figure 5: Minimum seasonal (3 months) precipitation in England and Wales, 1766-2007



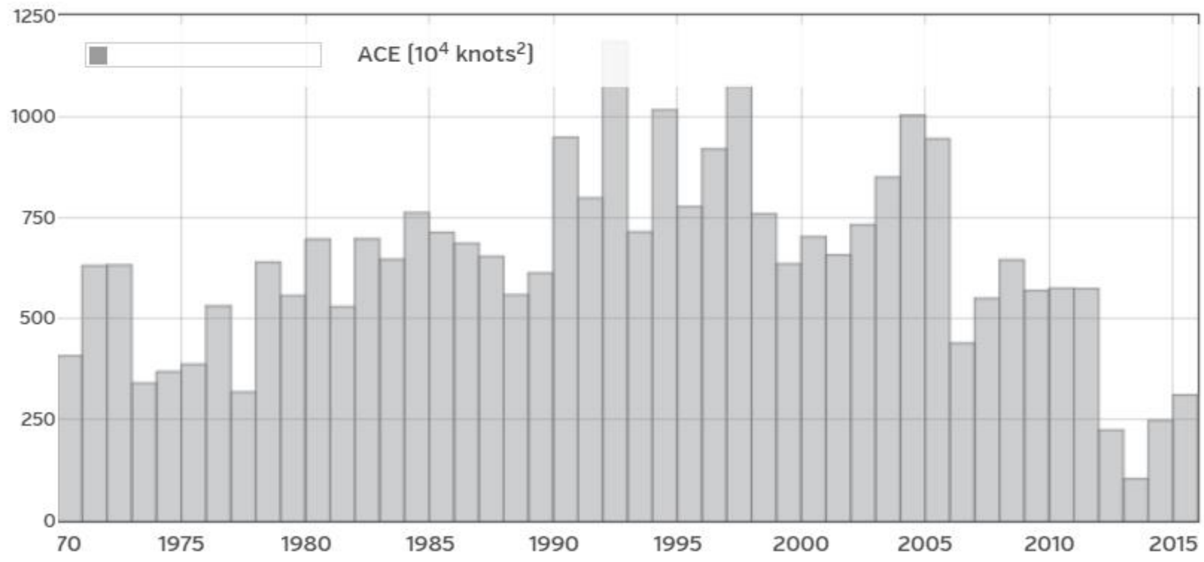
Source: Authors' elaboration based on data from the MetOffice http://www.metoffice.gov.uk/hadobs/hadukp/data/download.html). Formal reference: Alexander, L.V. and Jones, P.D. (2001) Updated precipitation series for the U.K. and discussion of recent extremes. Atmospheric Science Letters doi:10.1006/asle.2001.0025

Note: The blue line shows the minimum seasonal precipitation each year, the solid black line is the simple linear trend, and the dotted black line is the trend line minus 1.32 standard deviation, which in this particular series separates the 10% extreme low values observed.

3.5.Extreme wind

Hurricanes and cyclones all over the world have been monitored carefully using the Accumulated Cyclone Energy Index (see Figure 6). Accumulated cyclone energy, or "ACE," is used to express the activity and destructive potential of individual tropical cyclones and entire tropical cyclone seasons. ACE is calculated as the square of the wind speed every 6 hours, and is then scaled by a factor of 10,000 for usability. The ACE of a season is the sum of the ACE for each storm and takes into account the number, strength, and duration of all the tropical storms in the season. The damage potential of a hurricane is proportional to the square or cube of the maximum wind speed, and thus ACE is not only a measure of tropical cyclone activity, but a measure of the damage potential of an individual cyclone or a season[3].

Figure 6: Accumulated Cyclone Energy, Global, 1970-2015



Source: Weather Uunderground: http://www.wunderground.com/hurricane/accumulated_cyclone_energy.asp?basin=gl&MR=1

The ACE index increased steadily from 1970 to 1992, together with the global temperature, suggesting a correlation between temperatures and the force of cyclones. However, during the last 20 years, the index has been going down, while temperatures have stayed high, and the last four years have been the quietest on record, despite these four years being among the hottest on record. Instead it appears that there is a cyclical pattern in cyclone activity, and since we have just reached bottom, it is very likely that we will see increasing cyclone activity over the next few decades.

4. Most damaging climate events

There are three major kinds of damage from extreme climate events:

1) Loss of private and public physical assets
2) Loss of human life or health
3) Loss of natural assets.

The first two loss categories have been roughly monitored in some countries, and estimates are available that allow us to at least assess which type of climate events are the most damaging to

[3] http://www.wunderground.com/hurricane/accumulated_cyclone_energy.asp?basin=gl&MR=1.

physical assets and human health. Very little is known about the last category, though, and in this paper we will also ignore it.

Table 1 provides an estimate of cumulative damages from extreme climate events in the United States from 1980 to 2014. Only large events that caused at least one billion inflation-adjusted dollars of damage to physical assets are included in the analysis, but these billion-dollar events account for roughly 80% of the total losses for all combined severe weather and climate events (NCDC 2012; Smith & Katz, 2013). Half of all damage was caused by tropical cyclones, about 19% by droughts and about 14% by severe storms.

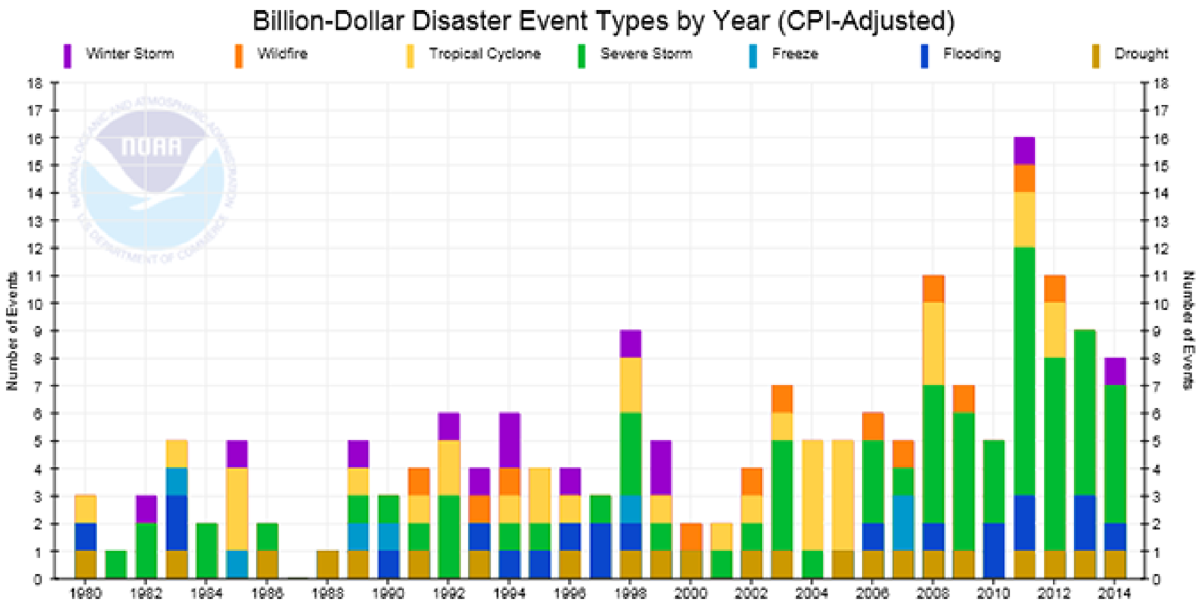
Table 1: Frequency, damage, percent damage, and percent frequency, by disaster type, across the 1980-2014 period for all billion-dollar events (adjusted for inflation to 2011 dollars)

DISASTER TYPE	NUMBER OF EVENTS	PERCENT FREQUENCY	CPI-ADJUSTED LOSSES *(BILLIONS OF DOLLARS)* [1]	PERCENT OF TOTAL LOSSES	AVERAGE EVENT COST *(BILLIONS OF DOLLARS)*
Drought	22	12.4%	$206	19.1%	$9.4
Flooding	20	11.2%	$88	8.2%	$4.4
Freeze	7	3.9%	$25	2.3%	$3.6
Severe Storm	70	39.3%	$155	14.4%	$2.2
Tropical Cyclone	34	19.1%	$539	50.0%	$15.9
Wildfire	12	6.7%	$26	2.4%	$2.2
Winter Storm	13	7.3%	$37	3.4%	$2.8

Source: NOAA : http://www.ncdc.noaa.gov/billions/summary-stats.

The losses have been going up over time (see Figure 6), but mostly because the amount of real estate exposed to risk is increasing over time. This upward tendency is very likely to continue as coastal real estate increases and as cyclone activity enters its more active phase again.

Figure 6: Evolution of billion-dollar disaster events in the United States, 1980-2014



Source: NOAA website: http://www.ncdc.noaa.gov/billions/time-series.

Cyclones not only cause the most material damage, but also the most deaths world-wide. The five most lethal cyclones in recorded history took place in:

1) Bangladesh, 1970, 500 thousand deaths;
2) Bangladesh and India, 1737, 300 thousand deaths;
3) Vietnam, 1881, 300 thousand deaths;
4) India, 1839, 300 thousand deaths; and
5) Bangladesh, 1584, 200 thousand deaths[4].

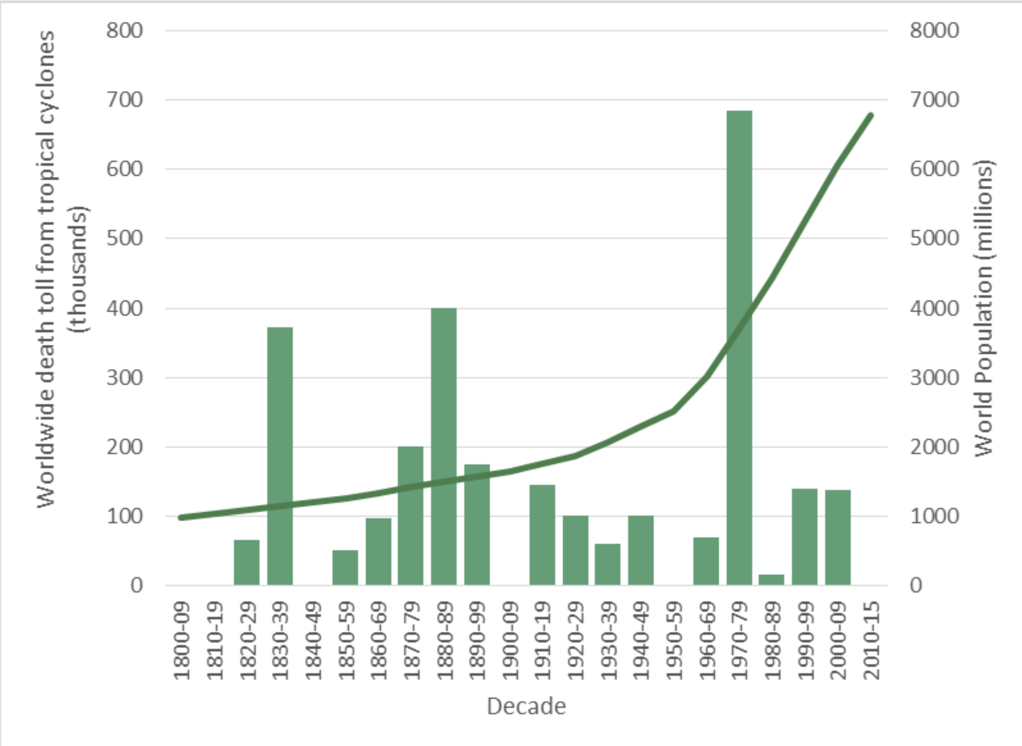
The vulnerability of countries depends on the type and frequency of extreme weather events which they are exposed to. But, on the other hand, and even more so, it also depends on local capacities to deal with such events (i.e. early warning, disaster response capacities). For example, while Bangladesh is hit by only about 1% of the world's total tropical storms, this very vulnerable, low-lying country has suffered more than half of all deaths from tropical cyclones in recorded history (Ali, 1999).

In terms of cyclones, the most fatal decade was 1970-1979, when Bangladesh was first hit by a Category-3 cyclone that killed close to 500 thousand persons in November of 1970. Five years later China was hit by the typhoon Nina, which caused the Benquiao Dam to collapse, triggering a cascade of dam failures downstream and a total death toll of about 200 thousand. Figure 7

[4] See http://www.wunderground.com/hurricane/deadlyworld.asp?MR=1 for a list of the 35 most lethal tropical cyclones in World History

shows that the death toll is highly variable, but has generally been increasing together with the size of the world population.

Figure 7: Worldwide death toll from cyclones, 1800-2015



Source: Weather Underground: http://www.wunderground.com/hurricane/deadlyworld.asp.

With more and more people living in coastal areas exposed to tropical cyclones, both economic and human losses are likely to keep increasing, unless we vastly improve the quality of construction, and the systems of early warning and disaster response.

Fortunately, this seems to be feasible. Box 1 shows how Bangladesh managed to vastly reduce the death toll from cyclones through effective warning systems and well-planned disaster responses combined with general economic progress. Such efforts to reduce current vulnerabilities, especially in the most vulnerable countries and regions, would help reduce vulnerability, poverty and inequality.

Box 1: Disaster preparation efforts pay off in Bangladesh

In 1970, the world's most devastating cyclone to date, although at Category-3 not at all the strongest, claimed approximately 500,000 lives in Bangladesh. In 1991 a Category-4 cyclone hit Bangladesh again and claimed around 140,000 lives. Since 1991, the government, with the help of foreign technical and financial support, has established early warning systems, shelters along coastal areas, search and rescue teams and first-aid training and equipment. Bangladesh now has the capacity to evacuate hundreds of thousands of people from the path of floods and cyclones. When Sidr, a very strong, Category-4 cyclone struck Bangladesh in November 2007, the devastation it wreaked was widespread, but while Sidr was of similar strength as the cyclone of 1991, its death toll, 3,000 lives, was much, much lower.

Source: WHO & WMO (2012).

5. Analytical methods and tools

Which tools can help governments design and implement policies and initiatives that simultaneously reduce current vulnerability and inequality in relation to climate change and climate variability?

In this section we analyze a range of tools and evaluate their strengths and weaknesses in their capacity to answer this question.

Key questions that need to be asked when analyzing each tool are the following:

- To what extent does the tool permit distinction between households of different income levels? (0: not at all; 1: somewhat; 2: very well)
- Does the tool take into account climate variability? (0: not at all; 1: somewhat; 2: very well).
- Does the tool target a very specific vulnerability or more general vulnerability? (0: very specific; 1: intermediate; 2: very general).
- Does the tool address immediate problems or very distant problems? (0: very distant; 1: in a few decades; 2: now).
- Is the tool simple to implement or very complex requiring many different specialist skills? (0: very complex; 1: moderately complex; 2: simple).
- What is level of uncertainty associated with the tool (0: very high uncertainty; 1: moderate uncertainty; 2: little uncertainty).

Basically, we are looking for tools that rank as highly as possible in all these dimensions. This is a tall order, of course, and no single tool will achieve maximum score in all dimensions. But applying a combination of tools might help us design appropriate policies.

In the remainder of this section we will evaluate a number of tools in these 6 dimensions, in order to identify the ones that would be most useful for our specific purpose. The list is not necessarily complete, but does cover a very wide range of tools.

5.1. Gathering weather and climate data and making it publicly available for analysis

Data availability is a fundamental prerequisite for most of the subsequent tools and methods, and countries with good data are clearly better equipped to deal with climate change and climate variability than countries with no data.

Weather, however, does not respect national borders, and international collaborative efforts clearly make sense, both to generate accurate weather forecasts, to build effective disaster warning systems, and to record and analyze historical data.

With automated weather station equipment, little local capacity is needed to gather the data, but in order to reduce vulnerability and inequality, a special effort should be made to make sure that all countries and regions are integrated into and benefit from the international efforts. That means international support for strengthening national weather agencies and for the timely dissemination of weather data and disaster warnings.

Our assessment of this line of work, in terms of the 6 key questions explained in the beginning of this section is the following:

Addresses inequality: 1 (if investing in the data collection and dissemination capacity in poor countries)
Takes into account climate variability: 2
Addresses general vulnerability: 0
Addresses immediate problems: 1
Is simple to implement: 1
Has little uncertainty: 2

5.2. Climate modelling

Almost all climate models in use are designed to simulate what will happen with the climate in different parts of the world if we increase the concentration of CO_2 in the atmosphere. While they all agree it will cause an increase in temperatures, and that there will be an increase in precipitation as a consequence, there is little agreement about the magnitude of the temperature increase and where the additional precipitation will fall. Since they model the distant future, climate models are not very useful for informing immediate policies to reduce vulnerability and inequality.

Climate modeling, when checked and validated against climate data, is useful for understanding our very complex climate systems and for assessing possible future climate change and its drivers. Despite the frequent claims that “the science is settled,” more research is needed to improve the out-of-sample forecasting abilities of the climate models. Currently, this ability is very low, suggesting that they are overfitted to past data, and model random variations rather than the true underlying data-generating process.

As a means of reducing vulnerability and inequality, our assessment indicates that climate modeling is not very useful:

Addresses inequality: 0
Takes into account climate variability: 1
Addresses general vulnerability: 0
Addresses immediate problems: 0
Is simple to implement: 0
Has little uncertainty: 0

5.3.Early Warning and Disaster Risk Management Systems

Early Warning systems can be defined as the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss. This definition does not include a reference to the time scale on which a warning is given. Early Warning Systems include a chain of concerns, namely: understanding and mapping the hazard; monitoring and forecasting impending events; processing and disseminating understandable warnings to political authorities and the population, and undertaking appropriate and timely actions in response to the warnings.

According to UNISDR & DKKV (2010), a complete and effective early warning system comprises four elements, spanning knowledge of the risks faced through to preparedness to act on early warning. Failure in any one part can mean failure of the whole system. The “four elements of effective early warning systems”, the Early Warning Chain, include the development and operation of early warning systems in regard to: (a) knowledge of risks; (b) monitoring and warning services; (c) warning dissemination and communication; and (d) emergency response.

a) **Risk knowledge:** Risk knowledge of the sub-regional or even small scale impacts of climate events on communities and their livelihoods is required, to allow a useful conception of Early Warning Systems. Assessments of risks require systematic collection and analysis of data and should consider the dynamic nature of hazards and vulnerabilities that rise from processes such as urbanization, rural land-use change, environmental degradation and climate change. Risk knowledge can help to enumerate risks related to climate change impacts and to prioritize risks that require further attention, giving priority to those affecting the most vulnerable regions and communities, thus helping reduce vulnerability, poverty and inequality.

b) **Monitoring and warning services:** Spatial and temporal changes in risk patterns resulting from changed vulnerability and the “new dimensions” of natural hazards (intensity, frequency, distribution) may introduce the need for adapting the distribution of early warning systems. Beyond that, areas increasingly affected by droughts or other hazardous events may face the phenomenon of climate induced migration; strong environmental changes may strengthen processes like rural exodus and urbanization. These processes can thus contribute to a changed distribution and vulnerability of people who have to be warned. Social changes (e.g. improper changes in land-use patterns in growing urban areas), environmental changes such as changes in vegetation cover may also alter the discharge of rivers and introduce flood events or facilitate hydrological droughts with consequences for irrigation, farming and livelihoods.

c) **Warning dissemination and communication:** institutions in charge of dissemination and communication may face the problem of adapting their concepts for disseminating and communicating early warnings because of new risk patterns. Increasing magnitudes of events requires dissemination with a longer lead-time in order to enable people to get prepared. Changing/increasing regional scales of events requires a regional extension of dissemination and communication lines.

d) **Emergency response:** Existing contingency and preparedness plans should be updated; they should consider climate change projections and vulnerability and capacity assessments. Existing information about climate change projections should be incorporated into existing plans (especially regional investigations but also national and international initiatives). Increasing frequencies/shorter return periods of events will pose a challenge to response capabilities and structures. As longer term possibilities for early warning response capabilities move out of the sectors of preparedness and response and enter the area of development decisions, the number of actors to involve has to increase; emerging potentials have to be explored; and available tools have to be integrated.

Summary assessment:

Addresses inequality: 2 (if implemented in poor countries and poor areas)
Takes into account climate variability: 2
Addresses general vulnerability: 1
Addresses immediate problems: 2

Is simple to implement: 0
Has little uncertainty: 0

5.4. Economic Modelling of Climate Change Impacts using Integrated Assessment Models

Although economic analysis of climate change and adaptation is crucial for forming informed policy actions, the economics of climate change has remained understated. Climate science and related biophysical processes have received much of the attention and effort by researchers and policy makers. In order to fill this gap, applied studies started using multidisciplinary approaches, integrating climate, environmental and economic expertise, mostly within Integrated Assessment Models (IAMs), which represent the complex cause-effect relationships between climate change, economic growth, and policy options.

According to Elbehri and Burfisher (2015), “climate change and its complex manifestations have brought together different knowledge disciplines from climate science, biophysical processes and socio-economic drivers all the way to issues of geography and sociology. Each of these disciplines contributes to our understanding of climate change effects; but only when fully integrated do we form a more complete assessment that can translate into policy action.”

IAMs represents an integrating framework that better incorporates biophysical processes with socio-economic analyses, yielding a stronger use of inter-disciplinary approaches. For this purpose, IAMs integrate in the analysis a group of specialized set of models, including:

- Climate models
- Pathway models
- Economic models

Climate models: Global climate models, or General Circulation Models (GCMs), are numerical models that apply known physical, chemical and biological principles to simulate the interaction of the atmosphere, oceans, land surface, snow, ice and permafrost in determining the earth’s climate. GCMs describe climate changes over relatively large spatial and temporal scales. GCM models carry out predictions for temperature, a variable that is relatively consistent over large spatial scales, and for precipitation, a variable influenced by smaller scale topographical features and cloud formations (McClusky and Qaddami, 2011). GCMs simulate a common set of greenhouse emission scenarios that describe broad story lines of alternative, stylized future paths and the interrelationships among five drivers of GHG emissions: population, economic and social development, energy technology, land use, and government policies.

Pathway models: Climate change operates indirectly, through multiple pathways, to affect economic activity and human well-being. According to Elbehri and Burfisher (2015), pathway models quantify the impacts of climate change and generate data used as inputs (or shocks) into economic models. Pathway models describe the biophysical effects of changes in temperature, precipitation and CO_2 on intermediate variables, such as crop yields, human health, and plant pests and diseases. Sea level rise reduces the land available for cultivation and other economic activities. Storms and flooding can destroy infrastructure, raising the costs of transportation and communication in all sectors of an economy. Climate change also affects hydrological processes and alters surface and groundwater dynamics, with significant impacts on agriculture and non-agriculture water supply.

Economic models: Economic models use the results of climate models and pathway models as input to evaluate the complex economic impacts of climate change. Different modelling types are applied depending on the research question, the scale (farm, sector, national or global) and the actors targeted (farmers, resource managers, firms, consumers, governments. Economic models are grouped between sectoral and household (or farm) types. Models focus on agriculture, distributional issues, food security, trade and other important drivers. Models can be grouped between sector-level models and farm and household models.

Integrated assessment models evaluate the situation far into the future, which means that the level of uncertainty is going to be extremely high. In these models, uncertainty is compounded due to large uncertainty in each of the sub-components of the models multiplied over many, many years. No economic models, for example, can adequately model even the baseline scenario, as they cannot take into account the currently unknown technological progress that is bound to happen over the next many decades. If we do not foresee what the world looks like by the end of this century, we obviously cannot determine what the impacts of climate change would be.

Assessment:

Addresses inequality: 1 (they potentially can)
Takes into account climate variability: 0
Addresses general vulnerability: 1
Addresses immediate problems: 0
Is simple to implement: 0
Has little uncertainty: 0

5.5.Cost-Benefit Analysis of Climate Change

Cost-Benefit Analysis (CBA) of climate change is a systematic approach to estimating the strengths and weaknesses of alternatives strategies aimed at coping with the effects of climate change. It is a systematic process for calculating and comparing benefits and costs of climate change impacts and of strategies (mitigation vis-à-vis adaptation) aimed at coping with their effects.

According to Agrawala et al. (2011) "A clear understanding of adaptation processes, autonomous or planned, along with a reliable quantification of their costs and benefits is fundamental for at least two reasons. The first reason is to assess the full cost of climate change. This is composed of three interdependent components: the cost of adaptation, the cost of mitigation, and residual climate damage. The second reason is to provide normative indications regarding efficient climate policy mixes. From a policy perspective, resources need to be allocated efficiently between different adaptation strategies on the one hand and between adaptation and mitigation strategies, on the other hand. This can only be done if costs and benefits of the different options are clearly determined."

According to the IPCC Fourth Assessment Report (AR4) published in 2007, economic analysis is asked to provide insights to policy makers on the cost and benefits of adaptation, the optimal resource allocation between adaptation and mitigation, their optimal timing, and their distributional implications. The IPCC Fourth Assessment Report concluded that [p.737]: "… there is […] a need for research on the synergies and trade-offs between various adaptation measures, and between adaptation and other development priorities. […] Another key area where information is currently very limited is on the economic and social costs and benefits of adaptation measures".
The analysis of the results of different modelling exercises show the importance of distinguish between cost-benefit and cost-effective analyses. The former aims at determining the first-best balance between adaptation and mitigation, given the respective costs and benefits. The latter approach aims at identifying the least-cost combination of adaptation and mitigation consistent with a given policy target, independently on the optimality of the policy objective.

Like integrated assessment models, cost-benefit analysis also evaluate the situation far into the future, with extremely high levels of uncertainty due to the integration of many different types of uncertainty (climatic, economic, technological). It thus offers little help to address immediate problems of vulnerability, poverty and inequality.

Assessment:

Addresses inequality: 0

Takes into account climate variability: 0
Addresses general vulnerability: 0
Addresses immediate problems: 0
Is simple to implement: 0
Has little uncertainty: 0

5.6.Resilient crop development

Crop improvements have been going on for thousands of years, but recent technological developments in genetics mean that we have become much more efficient at developing crops with certain desirable traits, and we can now modify crops so that they produce higher yields and thrive under different climatic conditions.

These technological advances can potentially be very helpful in reducing current vulnerabilities, poverty and inequality, if used to develop more resilient and more nutritious versions of the crops that many poor people rely on (e.g. rice), and if developed by public research institutes that make this technology available for poor farmers.

However, popular fears have created a very harsh regulatory environment for genetically modified foods, and the implications of these restrictive regulations are that only the most powerful companies in the world can shoulder the exorbitant costs to get GM seeds officially approved, and the companies of course try to recover these costs from their customers, which include poor farmers. In contrast, universities and research centers, with much more modest innovation and product development budgets, have little chance of getting over the bureaucratic hurdles, even if they have the technical expertise to develop crops that could directly benefit the poor, by making them more resilient to droughts, heat or inundations.

Big foundations, like the Bill & Melinda Gates Foundation, are trying to alleviate this problem by supporting the development of climate resilient, pest resilient and more nutritious crop species by specialized public research centers, such as the Bangladesh Rice Research Institute, the African Agricultural Technology Foundation, the International Centre for the Improvement of Maize and Wheat, among others.

Assessment:

Addresses inequality: 1 (only if targeted especially at crops mostly consumed by the poor)
Takes into account climate variability: 2
Addresses general vulnerability: 1
Addresses immediate problems: 2

Is simple to implement: 0
Has little uncertainty: 2

6. Conclusions and recommendations

Inequality both between and within countries is staggering, and climate change, extreme climate events, and other adverse shocks threaten to further aggravate this inequality, as poorer households tend to be more vulnerable and suffer more from adverse shocks and stresses than richer households. To counteract this tendency, it is important that global and national climate change policies are designed specifically to reduce the vulnerability of the poor and decrease inequality.

In this paper we have discussed what kind of research and tools can help inform the design of smart policies that simultaneously reduce vulnerability, poverty and inequality. We argued that such tools need to: 1) explicitly address inequality; 2) take into account climate variability, rather than just climate change; 3) target general vulnerability, rather than very specific vulnerabilities; 4) address immediate problems, rather than distant threats; 5) be simple to implement, so as to be feasible for those who need it most; and 6) involve low or moderate levels of uncertainty.

We found that disaster risk management systems and resilient crop development efforts are very worthwhile efforts as they can be targeted to address the current vulnerabilities of poor people, while also helping to reduce future risks from adverse climate events. For both, good weather data collection and analysis is a necessary input.

In contrast, integrated assessment models are designed to assess problems in the distant future and are thus not very helpful to inform current adaptation policies and alleviate current problems of vulnerability and inequality. In addition they involve so much uncertainty that they cannot even be used to help design very long term infrastructure (such as hydroelectric power plants). Table 2 summarizes the assessment of the different tools.

Table 2: Summary evaluation of research tools for reducing vulnerability, poverty and inequality

A. Addresses inequality
B. Takes into account climate variability
C. Addresses general vulnerability
D. Addresses immediate problems
E. Is simple to implement
F. Has little uncertainty

Tool	A	B	C	D	E	F	Total score	Main strengths and weaknesses
Gather, publish, and analyze climate data	1	2	0	1	2	2	8	Investments in data collection can be targeted at poor areas, where they are currently missing; it is necessary for risk assessments and the development of early warning systems; it helps us understand what is happening with the climate and it is necessary to test climate models.
Climate modeling	0	1	0	0	0	0	1	Helps us improve our understanding of how the climate system is working; but it does not really help the poor or solve any concrete problems.
Early warning and disaster risk management	2	2	1	2	0	0	7	Can be targeted at the poorest and most vulnerable regions; can dramatically reduce human and capital losses from recurring extreme climate events; can avoid plunging people into desperate poverty due to disaster.
Integrated Assessment Models	1	0	1	0	0	0	2	Could potentially identify the population groups most likely to suffer from future climate change and who are currently most vulnerable; does not address climate variability; does not solve any immediate problems.
Cost-benefit analysis of climate change	0	0	0	0	0	0	0	Does not help the poor; does not deal with climate variability; does not solve any concrete, immediate problems.
Resilient crop development	1	2	1	2	0	2	8	Can be targeted at the crops of poor people; it helps farmers become less vulnerable to existing climate variability; could help to make food production and food prices more stable; solves immediate problems of crop losses.

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