people with greater access to energy, including 300 million people unconnected to an electrical grid. India's INDC target for 2030 is to reduce GDP-based emissions intensity by 33–35% compared with 2005 levels. This target combined with estimates of long-term GDP from the Organization of Economic Co-Operation and Development suggest that India's CO_2 emissions could grow to about 4.2–4.5 Gt CO_2 yr^{-1} by 2030. Increasing emissions to ~4.5 Gt CO_2 yr^{-1} would raise India's per capita emissions to ~3.0 tCO_2 yr^{-1} per person, still well below current values for China (7.1 tCO_2 yr^{-1}) and the US (17.4 tCO_2 yr^{-1}). For global CO_2 emissions to peak quickly, part of India's new energy needs must come from low-carbon technologies. However, India had only 60 GW of low-carbon capacity installed by the end of 2014, and only 3 GW of solar power (Supplementary Fig. 1). A more robust electrical grid and a dramatic rise in renewables are greatly needed. Many other emerging economies and lower-income countries are in a similar position.

We have shown that the high growth rates in global CO_2 emissions prevalent since the early 2000s ceased in the past two years, at least temporarily, despite robust growth in global economic activity (Figs 1 and 2). Underlying trends in some emerging and established economies suggest that structural changes in their economies and energy systems are already leading to emission reductions. However, China's emissions growth rate will strongly influence this outcome over the next decade.

Whether the unexpectedly low growth rates in CO_2 emissions observed in 2014 and 2015 are a first sign of an approaching global peak in emissions is unclear. Current INDC pledges suggest that, even if emissions were to peak soon, global emissions would still take years to decline substantively. An acceleration in the transformation of energy use and production is needed to set global emissions on course to complete decarbonization, as required for climate stabilization. ❐

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Additional information

Supplementary information is available in the online version of the paper.

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COMMENTARY:

Food security under climate change

Thomas W. Hertel

Using food prices to assess climate change impacts on food security is misleading. Differential impacts on income require a broader measure of household well-being, such as changes in absolute poverty.

The implications of climate change for food security have recently received attention within the IPCC, culminating in an Expert Meeting in Dublin, Ireland (May 2015), to discuss assessment options. During the meeting, the need for new "metrics for measuring food security across local and regional contexts" was clearly identified. Up to this point, the focus has mainly been on food production (availability) and price[1]. This historical focus of the literature on production impacts typically leads global change researchers to equate higher food prices with diminished food security[2,3]. However, this linkage was challenged in Dublin as being misleading at best, and altogether wrong in some cases. The food price metric wholly ignores the impact of climate change and agricultural prices on household incomes. Yet household food consumption depends critically on both prices and income. If climate change raises incomes for some households, this could dampen, or even reverse, changes in food consumption, despite rising prices.

Nutritional outcomes

Apart from the ambiguous impact of climate change on incomes and consumption, a more general question is whether food intake is the best metric for assessing potential changes in nutrition. After all, nutrition outcomes are far more complex than the simple volumetric consumption of agricultural products would suggest[4]. Households often respond to food crises by reducing dietary diversity to maintain caloric intake. Nutrition outcomes also depend on the distribution of food within the household, health, education, sanitation, shelter from the elements, and protection from violence. Researchers must broaden the indicator of household well-being to encompass these other determinants of food security and nutrition outcomes. The absolute poverty measure used in international comparisons seeks to do this by factoring in the amount of income required to meet not only the minimal level of food consumption, but also other subsistence requirements[5].

Agriculture-dependent households

Near-term uncertainty notwithstanding, it is clear that, by 2100, adverse yield impacts of climate change will dominate, thereby leading to higher world prices[1]. As all households consume food, climate impact analyses generally conclude that all households will be hurt by the price rise, with the size of the loss, relative to income, rising with the share of income devoted to these commodities. However, this view neglects the impacts on incomes — particularly incomes of those associated with agricultural activity. This point is illustrated by the 2012 drought in the United States where maize yields fell by an average of 25%, relative to baseline. But prices rose by a greater percentage (roughly 50%, relative to baseline) due to the price-inelastic nature of demand[6]. Thus, aggregate national net cash receipts rose[7]. The lesson is that adverse productivity shocks can benefit the average agricultural producer, particularly if those reductions encompass a large share of global output.

Of course, those farm households that are 'net buyers' of food are likely to lose from higher prices — at least in the short term. However, over time, with substantial positive supply response, many net purchasing households may become net sellers, at which point they, too, benefit from higher prices. What about the farms that are wholly isolated from markets? With no rise in prices to offset a productivity loss, they will experience a loss in consumption equal to the reduction in output. Therefore, the critical question is this: how many of the world's food-insecure households will be market-linked food producers in the latter part of this century? And what proportion of these households will be net sellers of food? This is difficult to project. Based on past trends in urbanization and market integration, we can expect that there will be fewer farmers; however, with continued infrastructure investments, those that remain are expected to be more closely linked to commodity markets. How many of these farmers will remain impoverished is an important question.

Nuanced view

In the long run, a climate-induced slowdown in yield growth will raise prices, relative to baseline. This will have an impact on rural wages. These indirect impacts lead to a more nuanced view of climate impacts on poverty and food security. An early attempt to measure the effect of agricultural prices on rural wages in Bangladesh found that, over the short term, higher rice prices led to declining welfare for rural landless laborers[8]. However, after five years, the rise in wages resulting from sustained higher rice prices could be sufficient to boost overall well-being for many of these households. This finding has been further validated by the 2000–2010 food-price-induced rise in rural wages and subsequent poverty reduction in Bangladesh[9].

The possibility of higher food prices leading to a reduction in national poverty is given further credence by Derek Headey, who examines the impact on national poverty rates of higher food prices over the past decade[10]. He considers 300 different poverty 'episodes' drawn from the World Bank's library of household surveys. His statistical analysis reveals that, across this sample of countries and surveys, higher food prices have tended to reduce poverty. He attributes this tendency for higher food prices to reduce poverty to the price responsiveness of agricultural supplies and rural wages. Higher prices boost the incomes of the rural poor who often dominate the poverty statistics, thereby leading to national poverty reductions.

The foregoing studies by Headey and others do not differentiate between price rises driven by external market developments (for example, biofuels expansion in the US), as opposed to those resulting from localized disasters (for example, drought in Malawi). Implicitly, the authors have taken the price increases as external to the poverty system. Climate impacts will probably bring a combination of these two effects. What impact do localized disasters have on local labour markets? Evidence from flooding in Bangladesh[11] suggests the impact on rural wages is ambiguous. Floods that require replanting actually boost the demand for rural labour, thereby improving wages. However, floods that destroy the harvest are likely to have the opposite effect.

Household earnings

Clearly the impact of climate change on food security is more complex than portrayed in aggregate national-, continental- and global-scale integrated assessments. To capture heterogeneous income effects, analysis must differentiate households by sources of earnings. Figure 1 charts the distribution of absolute poverty in each of seven earnings strata for 31 developing countries, arranged by region, and in order of per capita income at the time of the survey. The blue segment identifies low-income households that earn 95% or more of their income from farming, and are therefore most likely to gain from higher food prices. As the colours evolve from dark blue to dark red, the earnings strata become less closely linked to farm prices, evolving from rural diversified to rural wage labour, urban diversified (often still receiving farm income), to non-agriculture self-employed, urban labour and transfer-dependent (dark red). From Fig. 1a, we see that many of the absolute poor in this sample of countries remain closely tied to farming. And, while the share of poor households linked to agriculture declines with rising national income (Fig. 1b), this share remains significant at higher levels.

National poverty

Back in 2010, Marshall Burke, David Lobell and I used 15 of these stratified surveys, nested within a global economic model, to analyse the poverty impacts of an extreme climate change scenario for 2030[12]. We found that prices of staple crops would rise sharply and average poverty rates would fall for many diversified households and those specialized on farming. As a result, national poverty rates fall in about half of countries sampled, namely those experiencing a combination of lower than average climate-induced yield reductions,

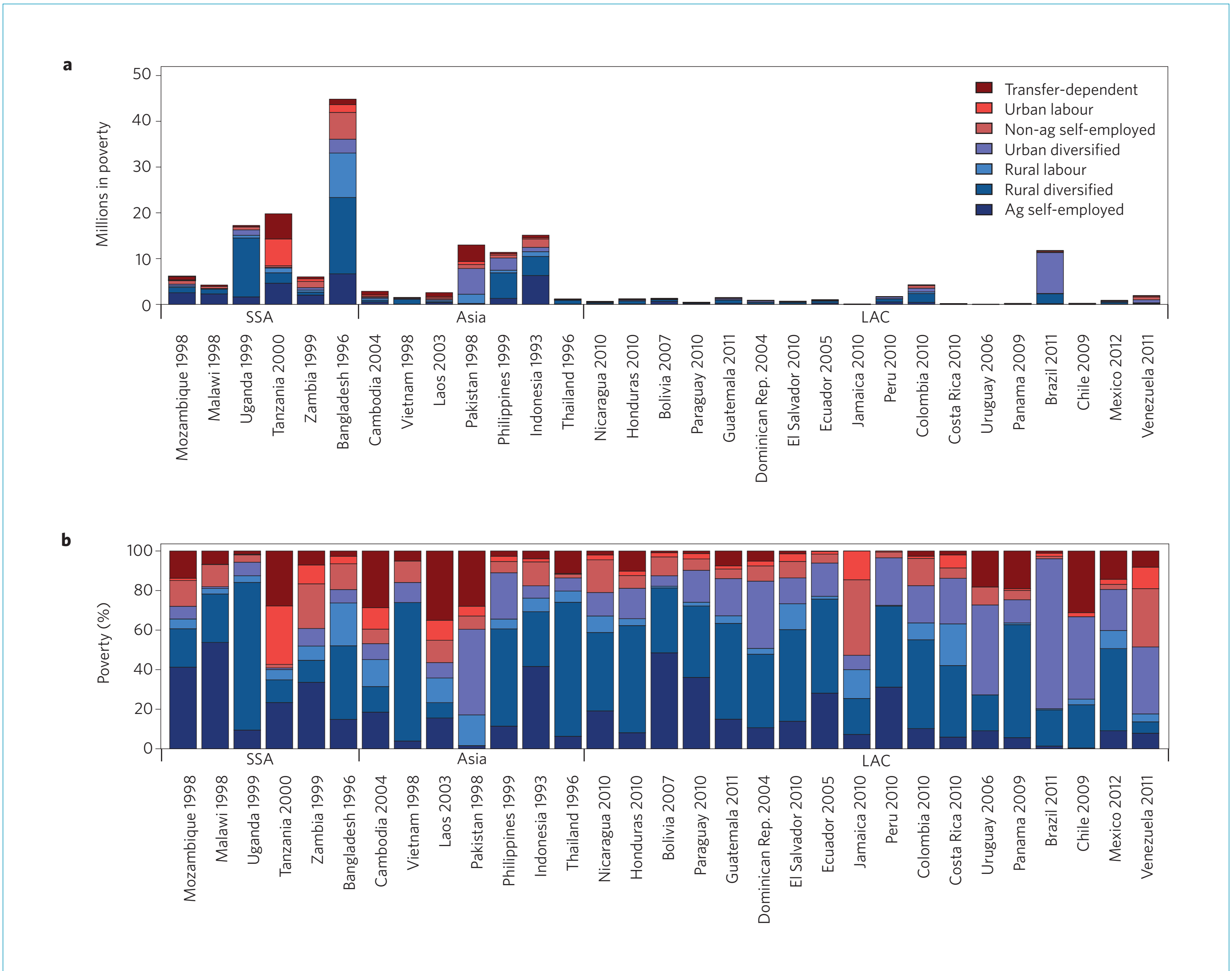

Figure 1 | Distribution of absolute poverty, by earnings stratum ($1 per day for surveys predating 2000, and $1.25 per day thereafter). **a**, Millions of people in poverty, by country. **b**, The percentage contribution of each stratum to national poverty, by country. Countries are grouped by region: sub-Saharan Africa, Asia and Latin America and the Caribbean. Within each region, countries are ordered by increasing per capita income (on the basis of purchasing power parity) at the time of the household survey. Earnings strata are colour coded (see mapping in **a**). They include households earning 95% or more of their income from transfer payments, urban labour, rural labour, self-employment in non-agriculture and agriculture self-employment. The two remaining strata comprise the residual, rural and urban diversified strata. For details on the construction of these strata, see Hertel and colleagues[15]. Figure prepared by German A. Marquez Alcala.

along with higher concentrations of rural poverty. However, in examining the impacts of future climate, we did not alter the current pattern of household earnings and poverty.

The real challenge in assessing the poverty and food security impacts of climate change is that not only are biophysical impacts uncertain, but the future distribution of the food-insecure population within the economy is unknown. Based on current projections[13], it seems that most of the additional population over the coming century will be added in urban areas of the developing world. This is of particular concern as the urban poor are likely to feel the full impact of the global food price rises without any offsetting income gains[9], thereby making them highly vulnerable to climate extremes, which are likely to occur more often in future[14]. These demographic trends notwithstanding, it is likely that pockets of rural poverty will persist, and could even continue to dominate absolute poverty in the world's poorest countries well into the twenty-first century. Future research on the food security impacts of climate must devote more attention to poor households, their nutritional status, where they live and how they earn their living. We must move beyond the convenient, but often misleading, food-price metric for assessing the impact of climate change on food security. ❐

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COMMENTARY:

The rise of demand-driven climate services

Tiago Capela Lourenço, Rob Swart, Hasse Goosen and Roger Street

With the concept of climate services rapidly climbing research and research-funding agendas worldwide, the time is ripe for a debate about the objectives, scope and content of such services.

Over the past decade, multiple frameworks and agendas have been proposed for climate services[1–7]. These initiatives have tried to keep up with an ever-growing knowledge base, a more informed appreciation of the importance of climate for decision-making, and a greater demand for all sorts of climate-related information. Yet there are still plenty of questions left about what climate services actually constitute, who their users are, how they relate to research, and what their value is for innovation, economic growth and development. Are the users of climate change research and of climate services necessarily the same? To what extent should the future of climate change research and of its researchers be inspired by the needs of service clients?

The World Meteorological Organization's (WMO) Global Framework for Climate Services (GFCS)[4,6] defines climate services as "providing climate information in a way that assists decision-making by individuals and organizations. A service requires appropriate engagement along with an effective access mechanism and must respond to user needs." It identifies a set of priority areas and sectors, but does not define which decision-making processes need what information, or why they need it. Rather the focus is on what information is available and the format in which it can be delivered[6].

The American Meteorological Society (AMS)[5] defines climate services as "scientifically based information and products that enhance users' knowledge and understanding about the impacts of climate on their decisions and actions. These services are made most effective through collaboration between providers and users." Again, multiple sectors are identified as important, but the focus is placed on the communication and provision of past, present and future climate data[5].

The Climate Services Roadmap[7] recently launched by the European Commission takes on a broader perspective where climate services can cover the "transformation of climate-related data — together with other relevant information — into customised products […] and any other service in relation to climate that may be of use for the society at large." Climate services are expected to include "data, information and knowledge that support adaptation, mitigation and disaster risk management", covering a broad spectrum of decision-making processes[7].

The historical evolution of climate services is analogous to that of weather services, starting from an observation-based emphasis and expanding to predictive services as capabilities increased and demands were more clearly articulated[1]. Partly because of limited effectiveness, their scope has shifted towards a more user-centred approach, focusing on data stewardship and active partnerships[8]. As yet, discussions about climate services have been largely dominated by a supply-side perspective and framed from a standpoint of climate observations and modelling.

Market development

A considerable market is expected to develop in the near future, much of it from the private sector for the private sector, as it is for weather forecasting services (for example private consultancies for media, farmers, utilities, shipping and air traffic). But the roles of public, private and academic sectors are sometimes difficult to distinguish in climate services[5]. The boundary between the public and private dimension is not easy to draw[7], and assessing the value of these services for public and private sectors is complex[5]. All of this makes it difficult to establish clear market boundaries.

Comprehensive information about existing climate services is not readily available, suggesting that a market for such services and products may be growing slowly or not at all. It has been suggested that the current business area is relatively small, in both number and size of involved organizations[7], and/or too fragmented[4]. Alternatively, could it be that the climate