REVIEW ARTICLE

# Climate Change and Agriculture in the United States

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## *Introduction and Context*

The response to global warming of anthropogenic origin can be divided, broadly speaking, into two categories of actions. The first is mitigation, which refers to the effort to limit the rise in global temperatures by limiting, and eventually possibly eliminating, the emissions of greenhouse gases – which are the ultimate cause of global warming – into the atmosphere. The second is adaptation, which refers to measures and initiatives that help human society's production systems and the organisation of human activity cope with the consequences of global warming, and the effects and impact of such warming on the earth's geosphere and biosphere.

The extensive literature on adaptation to climate change often carries the implication that adaptation is the concern of less-developed societies, while mitigation is the concern of developed societies.[1] While it is true that the majority of the people of the global South are the most vulnerable to climate change,[2] a one-sided view of this matter can obscure the fact that a variety of institutions in the developed nations

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[1] The United Nations Framework Convention on Climate Change (UNFCCC), in Article 3.1 and Article 4.2(a), in fact enjoins developed countries (and commits them) to take the lead in mitigation (UNFCCC 1992). While calling on all countries to undertake adaptation action, the Convention also commits developed countries, in Article 3.2 and Article 4.4, to specially assist developing countries that are particularly vulnerable to the impact of climate change (ibid.).

[2] The somewhat weaker consensus formulation of the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, in Chapter 5, Section 5.2, states: "Moreover, there is increased evidence that low-latitude and less-developed areas generally face greater risk, for example in dry areas and megadeltas. New studies confirm that Africa is one of the most vulnerable continents because of the range of projected impacts, multiple stresses and low adaptive capacity. Substantial risks due to sea level rise are projected particularly for Asian megadeltas and for small island communities." This catalogue of the regions at higher risk clearly includes a large proportion of the developing world (IPCC 2007).

are seriously engaged with the issue of adaptation. This engagement ranges over an entire spectrum of actions, from research to the actual implementation of specific adaptation plans.

Globally, one of the most important sectors with respect to adaptation in the era of climate change is agriculture.[3] Agriculture in the developed countries represents a very minor share of their national incomes. Nevertheless, given the productivity of agriculture in these countries and the size of their economies, agriculture in the developed countries represents a significant component of global agriculture. Hence, the impact and possible adaptation of agriculture to climate change in the developed countries is an important global issue.

In particular, we may consider, *prima facie*, four reasons why the impact of climate change on developed-country agriculture should be of more than domestic significance. If we consider the member-countries of the Organisation for Economic Cooperation and Development (OECD) as a proxy for the Annex-I parties to the United Nations Framework Convention on Climate Change (UNFCCC),[4] projections by the OECD and the Food and Agriculture Organisation (FAO) of the United Nations suggest that, currently and in the short to medium term, OECD countries will continue to contribute a significant part of global food production (Table 1). In terms of global food availability, agricultural production in the developed countries is therefore significant.

Secondly, projections suggest that the developed countries will continue to be net exporters of food, while the less-developed countries will continue to be net importers of food (Tables 2 and 3)..[5] Given the possibility that less-developed countries, especially in lower latitudes, will suffer more than others from the impact of climate change, the availability of developed-country surpluses for export is a matter of importance for the future of global food trade and consumption. Further, in the event that the impact of climate change on tropical and sub-tropical agriculture is even more dramatic than currently predicted, issues of the global availability of food become correspondingly more important.

Thirdly, it is essential to know the extent of the impact of climate change on developed-country agriculture. If the impact is significant and accompanied by a decline in the aggregate production of agricultural commodities in the developed countries, new pressures on global food markets could have very negative consequences for the

[3] For a general, introductory review of climate change and agriculture, with special reference to India, see Jayaraman (2011).
[4] In the terminology of the UNFCCC, Annex-I parties refers to those developed countries and other countries that commit themselves to mitigation action and various other related actions that would demonstrate that developed countries are taking the lead. However, this does not imply that the UNFCCC imposes any binding quantitative commitments on these countries (UNFCCC 1992).
[5] Based on data from OECD–FAO (2011).

**Table 1** *Projections of the shares of OECD* member-countries in the world's production of wheat and coarse grains*** in per cent

| Crop | Years | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2008–09 to 2010–11*** | 2011–12 | 2012–13 | 2015–16 | 2016–17 | 2017–18 | 2018–19 | 2019–20 | 2020–21 |
| Wheat | 42 | 41 | 40 | 40 | 40 | 39 | 39 | 39 | 39 |
| Coarse grains | 51 | 51 | 51 | 50 | 50 | 50 | 50 | 50 | 50 |

*Notes*: * OECD = Organisation for Economic Cooperation and Development.
** "Coarse grains generally refers to cereal grains other than wheat and rice; in the OECD countries, those used primarily for animal feed or brewing" (http://stats.oecd.org/glossary/detail.asp?ID=369, viewed on 20 June 2013).
*** Estimates of production.
*Source*: Based on data from OECD–FAO (2011).

**Table 2** *Estimates and projections of the world's wheat production and trade* in million tonnes

| Sector | Wheat production | | Wheat imports | | Wheat exports | |
|---|---|---|---|---|---|---|
| | Average for 2008–10 (estimate) | 2020 (projection) | Average for 2008–10 (estimate) | 2020 (projection) | Average for 2008–10 (estimate) | 2020 (projection) |
| World | 674.01 | 745.90 | 128.31 | 144.90 | 128.98 | 144.66 |
| Developed countries | 366.67 | 398.91 | 26.09 | 25.40 | 113.56 | 123.36 |
| Less-developed countries | 307.34 | 346.99 | 102.22 | 119.51 | 15.42 | 21.30 |

*Source*: Based on data from OECD–FAO (2011).

**Table 3** *Estimates and projections of the world's coarse grain* production and trade* in million tonnes

| Sector | Coarse grain production | | Coarse grain imports | | Coarse grain exports | |
|---|---|---|---|---|---|---|
| | Average for 2008–10 (estimate) | 2020 (projection) | Average for 2008–10 (estimate) | 2020 (projection) | Average for 2008–10 (estimate) | 2020 (projection) |
| World | 1121.560 | 1320.710 | 114.289 | 136.477 | 120.988 | 142.626 |
| Developed countries | 612.504 | 704.650 | 32.295 | 34.568 | 87.821 | 100.422 |
| Less-developed countries | 509.056 | 616.061 | 81.994 | 101.909 | 33.167 | 42.203 |

*Note*: * "Coarse grains generally refers to cereal grains other than wheat and rice; in the OECD countries, those used primarily for animal feed or brewing" (http://stats.oecd.org/glossary/detail.asp?ID=369, viewed on 20 June 2013).
*Source*: Based on data from OECD–FAO (2011).

less-developed countries. Fourthly, in the context of mitigation, the widespread expansion of biofuel production to satisfy renewable energy demand could lead to the diversion of cereals from their use as food to use as fuel, with obvious consequences for global food markets. Indeed, it has been argued that the surge in food prices in 2006–08 was partly a consequence of the diversion of grain for use in biofuel production. It is also possible that the demand for renewable energy could lead to diversion of land itself for biofuel production.

## *Climate Change and Agriculture in the United States*

In view of these considerations, the publication under review, *Climate Change and Agriculture in the United States: Effects and Adaptation* (referred to hereafter as the Report) – a 140-page scientific and technical document produced and published by the Climate Change Research Office of the Agricultural Research Service of the United States Department of Agriculture (USDA) – is of much interest and relevance. Among the developed countries, the case of the United States is of particular importance. The United States is a major agricultural power, even if agriculture constitutes only 1 per cent of its GDP. The gross value of production of US agriculture in 2011 was of the order of US$ 219.15 billion (at constant 2004–06 US$), whereas the comparable figure for India was US$ 190.67 billion.[6] The United States is a major producer of the world's wheat, coarse grains, and corn (Table 4).

The United States is also a significant factor in world trade in agricultural commodities (see Table 5 below).

**Table 4** *The share of the United States in the world's production of wheat, coarse grains, and cereals, 2006–11* in per cent

| Share in world production of: | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|
| Wheat | 8 | 9 | 10 | 9 | 9 | 8 |
| Coarse grains | 28 | 32 | 28 | 31 | 29 | 28 |
| Cereals | 15 | 18 | 16 | 17 | 16 | 15 |

*Source*: Data compiled from FAOSTAT, available at http://faostat.fao.org (viewed on 5 June 2013).

**Table 5** *The share of the United States in the world's exports of wheat and cereals, 2006–10* in per cent

| Share in world exports of: | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|
| Wheat | 18 | 26 | 23 | 15 | 19 |
| Cereals | 30 | 31 | 30 | 23 | 26 |

*Source*: Data compiled from FAOSTAT (http://faostat.fao.org, viewed on 5 June 2013).

[6] FAOSTAT, available at http://faostat.fao.org, viewed on 5 June 2013.

The sheer volume of production in the United States is of significance; in addition, agriculture there occurs over a wide variety of agro-ecological zones, in each of which adaptation to the environment has taken place over many years and under conditions of increasing technological sophistication. The United States thus also offers an important and significant counterpoint to the problems of adaptation of agriculture to climate change seen in less-developed countries.

The Report under review follows on a study published in 2008.[7] In addition to issues of the direct impact of changing temperature and precipitation on crop and livestock production, this Report claims to build on the earlier one by its coverage of three important issues, namely, climate change adaptation processes, the economic impact of climate change on agriculture, and the indirect biological stresses on agriculture induced by climate change (Report, Ch. 1, p. 9).

Broadly speaking, the most significant finding of the Report is that, while US agriculture is expected to be fairly resilient to climate change in the short run, increasing temperatures in the range of 1–3 degrees centigrade and increasing precipitation extremes by mid-century are projected to lead to decreasing yields and farm returns. However, given the uncertainties in accounting for changes in pest pressures, ecosystem services, and adaptation constraints, current projections could well be underestimating production costs and yield losses (Report, Executive Summary, p. 2).

Livestock production appears more susceptible to temperature stress, especially due to the number of days of extreme heat. Indeed, one of the key findings of the Report is the danger posed by extreme temperatures and increased humidity to livestock, and the consequent effects on the production of animal products such as meat, eggs, and milk. The effect is expected to be more pronounced on livestock production systems that do not have adequate provision for partial or complete shelter for animals (ibid., p. 4).

The focus on economic losses and the manner in which developed-country agriculture is affected by climate change illustrates the distinctive nature of the vulnerability of agriculture in developed nations. Given the high levels of technological sophistication and investment in agriculture, potential economic losses can be very high.

Another aspect of US agriculture that is relevant to understanding its vulnerability is the extent of its specialisation. Alongside the rise in productivity of agriculture (total farm land has remained roughly at the same extent since 1900 even as productivity has risen), there has been a reduction, over a century, in the average number of different types of commodities produced per farm, which has fallen from approximately five in 1900 to a little more than one in 2000 (Report, Ch. 2, p. 11). As the Report notes,

[7] See CCSP (2008).

relatively large farms specialising in a single commodity can be prone to catastrophic losses due to insect attack, pathogens or extreme events as a consequence of climate change, even if they are the product of high levels of adaptation to current climatic conditions (ibid.).

Chapter 4 of the Report ("Climate Change Science and Agriculture") pays specific and detailed attention to – among other effects of indirect climate change – the behaviour of weeds and other invasive plants, insects, and pathogens. The interaction of crops and weeds under conditions of increasing carbon dioxide concentration and temperature continues to be an area that has been poorly studied (even less is known regarding this interaction if changes in precipitation and changes in nutrient availability are also taken into account). The major issue with pests is the possibility that their geographical distribution will change with changes in temperature and precipitation; thus, several insect species are expected to spread into regions where they were not known earlier. In the case of plant pathogens, a variety of possible outcomes are known. In general, if the host plant is able to survive change, so can the pathogens that are associated with the plant. Pathogens cause, even currently, a loss in production of approximately 11 per cent. Nevertheless, despite work on defining disease-process parameters, there appears to be little concrete advance beyond the decade-old acknowledgement of the complexity of the impact of climate change on plant diseases (Report, Ch. 4, p. 49).

## *Extreme Events*

An important feature of the Report is the attention it pays to the role of extreme events, always keeping in view the latest scientific results on the impact of extreme events on crop production.[8] It is now recognised that agricultural productivity depends crucially on *optimal* values of climate variables at critical stages of crop development, and that deviations from these values lead to sharp drops in productivity. This is a significant advance and goes beyond considering *average* values of climate variables, the method that dominated analyses of the impact of climate change on crop production till recently.

Extreme rainfall events, for instance, have been increasing between 1910 and 1996, with the increase in the top 99.9th sub-percentile of extreme events being 3.3 per cent per decade, while events in the top 95th percentile have been growing at only 1.7 per cent per decade (Report, Ch. 3, p. 23). It is forecast that climate change will lead to increases, by the end of the twenty-first century, in the number of hot nights and in the duration of very low rainfall events (Report, Executive Summary, p. 5).

[8] See, for instance, Lobell (2011). For an authoritative review of the significance of extreme events in the context of climate change and adaptation, see IPCC (2012).

Extreme events of different kinds, including hurricanes, drought, extreme rainfall, and intense storms could lead to substantial losses. Data show that the number of extreme events causing losses in excess of US$ 1 billion has been increasing between 1980 and 2011. The Report uses a study in the state of Iowa to illustrate the impact on agriculture of an increase in the number of extreme events as a result of climate change (Ch. 6, pp. 111–17). The Iowa study examines crop insurance and indemnity payments, the number of workable field-days (that is, days on which agricultural operations can be conducted without weather conditions that prevent field operations), and soil erosion rates. In the case of soil erosion, the Report warns that the extent of soil erosion could be severely underestimated in current models, that is, extreme events occurring as a consequence of climate change could have a much more damaging impact on soils than is currently reported.

Extreme events have yet to be properly integrated into yield projections for various crops. Yield projections are an important ingredient of various models that are used to assess the economic impact of climate change on agriculture. The Report notes, albeit implicitly, that yield projections that take extreme events into account predict more losses for US agriculture as a consequence of climate change than do models that do not account for such events.

### *Specific Production Systems*

Research on specific crops provides concrete information on their current and future vulnerability to climate stress and shocks. Chapter 5 of the Report (pp. 53–98), titled "Climate Change Effects on US Agricultural Production," summarises the current state of knowledge of the impact of climate change on major field crops, including rice, wheat, corn, soya, and cotton, as well as "specialty crops" (in the official US Definition, the term refers to fruit and vegetables, tree nuts, dried fruit, and horticulture and nursery crops, including floriculture).

The rates of growth of corn and soybean yields have declined on account of the effects of climate change despite the fact that statistical analysis of past yields also indicates that increasing carbon dioxide concentrations in the atmosphere have contributed positively to yield growth.[9] The Report notes that predicting trends in future production and yield under conditions of climate change remains a challenge on account of large variations at the regional level. These variations reflect local conditions where different stresses may combine in very complex ways. Nevertheless, broad future trends can be inferred, even though experimental results to validate these inferences would be welcome. In the southern parts of the United States, for instance, corn and soybean yields are likely to be affected by rising temperatures.

[9] The impacts of climate change on corn and soybean production are discussed in the Report, Ch. 5, pp. 61–63.

The Report also provides a detailed summary of climate change, and rice and wheat production. In rice production, the critical issues are water stress, both due to decreased availability and flooding in different locations, and the complex interaction between increasing temperatures, carbon fertilization, water availability, humidity, and pests and weeds (Report, Ch. 5, pp. 63–67). Here again, while the potential for changes in the current situation is clear, very little is known regarding the nature and magnitude of specific effects. Interestingly, even in the case of wheat, the Report emphasises water stress, noting that much of current US wheat production occurs in regions where water deficits limit yields in most seasons, and droughts can cause large-scale crop failures (ibid., pp. 67–69).

Apart from shortening the growing length of season and thus reducing yields, increasing temperatures will also tend to promote pests. In the United States, cold winters tend to limit pest populations; hence, rising winter temperatures will increase insect populations. Overall, the trends inferred from more than 35 model studies suggest that while climate change may have a beneficial effect on wheat production at higher latitudes, there will be negative effects at lower latitudes. While uncertainty dominates the picture as far as the future vulnerability of wheat production is concerned, the Report is nevertheless optimistic regarding the capacity of wheat production to adapt to changing climatic conditions. This optimism is based primarily on the historical adaptive capacity of wheat production in the US. Noting the wide variety of climatic conditions under which wheat production takes place, and the expansion of the areas and conditions in which the crop is grown, the Report suggests that the impact of climate change on wheat production could be manageable.

Specialty crops, annual and perennial, have a greater vulnerability to climate change since climatic conditions, both directly and indirectly, affect not only yield, but also the quality of the product, which is a critical consideration in determining the value of the product. The Report notes the nutritional significance of specialty crops, primarily fruits and vegetables, an emphasis often missing in discussions of adaptation in less-developed countries with its overwhelming attention towards cereal production (Report, Ch. 5, p. 75). A key factor for annual specialty crops (mostly vegetables, except for strawberries and melons) is the availability of water, apart from temperature increase itself (ibid., pp. 76–77), while the key factor for many perennial specialty crops (primarily a wide range of fruits) is winter temperatures that are sufficiently cold to account for their chilling requirements (this does not, of course, apply to citrus fruits) (Report, Executive Summary, p. 3).

Specialty crops are particularly susceptible to extreme events.[10] Excess precipitation, unusually warm or cold weather, high winds, and other such impacts at critical moments in the production cycle can lead to major losses in production and

[10] See various remarks in Report, Ch. 5, pp. 75–88.

consequent economic losses. In this context, the case of wine grapes and the wine industry attracts some particular attention in the Report (Ch. 5, p. 86). One study cited in the Report estimates that by the late twenty-first century, in a scenario where mean temperature increase would be beyond 3˚C with precipitation declines of 10 to 20 per cent, wine grape-growing areas would decline by as much as 81 per cent. Much of the current cropped area would become inhospitable to wine grape cultivation as a result of increased temperatures, and the areas where temperatures are appropriate would be regions that already suffer from excess moisture. Wine grape-growing is likely to adapt by shifting to warm climate varieties and wines of lower quality.

In contrast, the projections are that there will be, at all locations, a decrease in crop losses as a result of freezing, with these losses set to be 65 per cent lower in 2030 than at present and 80 per cent lower in 2090. Research shows that citrus fruits, too, are likely to experience higher yields (Report, Ch. 5, p. 89). These figures are from crop models that use so-called "business-as-usual" climate scenarios, which assume that carbon dioxide concentrations in the atmosphere will reach 445 ppm (parts per million) by 2030 and 660 ppm by 2090.

Animal farming and livestock products make up roughly half the total value of agricultural production in the United States (Report, Ch. 2, p. 11). Livestock are sensitive to both temperature and humidity. Body temperatures of animals are maintained in a narrow range, beyond which they may experience a variety of stresses. The productivity and health of livestock are possibly more susceptible to the number of days of extreme heat than to higher average temperatures. Humidity renders them more susceptible to diseases and pests. In general, the negative effect of warmer summers is expected to outweigh the positive effect of warmer winters, with unsheltered animals at greater risk than sheltered animals (Report, Executive Summary, p. 4 and Ch. 5, pp. 88–91). Even at present, the loss of productivity due to summer heat is estimated to cost the US swine industry approximately US$ 300 million a year (Report, Ch. 5, p. 89). Another important issue in this regard is the impact of climate change on fodder production and the natural availability of fodder in grasslands or other types of pasture. Grassland availability has steadily declined in the United States for a number of reasons, including changes in climate, and these pressures are likely to be exacerbated by climate change, though a number of scientific uncertainties remain (ibid., pp. 91–94).

## *Adaptation in US Agriculture*

The chapter in the Report on adaptation will be of some interest to those familiar with the literature on adaptation to climate change in less-developed economies, where the focus in the agricultural sector is on small-holder agriculture. As the Report acknowledges, much of the methodological and theoretical literature on adaptation has originated in the study of less-developed economies. Even so, a surprising feature of the useful summary of the literature that is provided in the Report is the *extent* to which the conceptual machinery of adaptation drawn from the less-developed country context is being utilised in understanding developed-country adaptation. It is somewhat amusing to see the methods used originally to study rural livelihoods among African pastoralists being applied to Australian agriculture, or the methods used in the study of semi-arid agriculture in Maharashtra in western India being applied to dairy farmers in north-eastern United States. While it may be argued that this only points to some of the universal features of adaptation in the agricultural sector, it appears more likely that the absence of a distinctive framework is a consequence of the fact that adaptation in the context of the United States has still not been taken seriously enough by the climate change community. As the Report notes, citing published literature, much of the focus of climate policy relating to the agricultural sector in developed countries has been on mitigation from the point of view of agriculture as a source of greenhouse gas emissions and as a means of carbon sequestration (Ch. 7, p. 124).

Nevertheless, in its coverage of adaptation issues the Report has some interesting observations to offer from the literature. It notes briefly that adaptations at the enterprise level that are based on the extension of existing farming practices may work in the short term but are in danger of being counter-productive in the long run (ibid., p. 135). In a section on risk assessment, the Report notes that decision-making under uncertainty must involve a range of strategies that deal with a range of possible outcomes, rather than selecting strategies that deal with single most likely or high-impact outcomes (ibid., p. 137).

But despite being one of the key issues studied in the Report, adaptation is discussed mostly in terms of specific technical strategies in managing specific crop production systems. For instance, resilience in the short term is expected to arise from adaptation behaviour such as

> expansion of irrigated acreage, regional shifts in acreage for specific crops, crop rotations, changes to management decisions such as choice and timing of inputs and cultivation practices, and altered trade patterns compensating for yield changes caused by changing climate patterns. (Report, Executive Summary, p. 2)

The Report notes that much of the research on the impact of climate change tends to focus on single effects, the results of which are then often used to recommend adaptation strategies that do not take the interactions between different effects into account (Ch. 7, p. 134). It appears that development of the policy aspects of adaptation in the United States is still in its initial stages, with many general observations and little that is specific, and much of the literature on adaptation strategies that is cited originates from other developed countries. Despite the invocation of sustainability, there is no exploration of the link between adaptation and sustainability in any significant manner, even though there has been long-standing criticism of the practices of US agriculture as being highly unsustainable.

Perhaps the most unsatisfying part of the Report is chapter 6, on the economic impact of climate change on agriculture. Given the high levels of uncertainty due to a number of reasons, estimates of the economic impact of climate change have sharply varying results, ranging from substantial benefits to US agriculture under climate change to substantial negative effects. Unfortunately, the Report does little more than catalogue the sources of uncertainty, a task that it does in a systematic manner. These include uncertainties arising from climate and yield projections; uncertainties involving the scope of analysis, including the number of sectors included in models and whether the analysis is regional or global; and uncertainties arising from socio-economic and technology projections, and other problems of methodology (Report, Ch. 6, pp. 103–08).

Results from several studies on the economic impact of climate change on US agriculture, presented in a single table in this chapter, suggest that the total economic impact of climate change may range from annual gains of approximately US$ 10 billion to losses amounting to as much as US$ 180 billion a year (ibid., Table 6.1, p. 102). The table is of little use to even a lay reader. It does not even present the economic losses or gains at constant prices, leaving it to the reader to convert 1990 US dollars to 1982 US dollars or 2000 US dollars. Nor does it present any comprehensible summary of the assumptions, whether regarding economic calculations or future climate projections, involved in each of these studies. It appears that the authors of the Report themselves do not take this chapter seriously, since no finding (indeed there is none to be presented) from this section is mentioned either in the Key Findings or the Executive Summary. The subject of economic losses in the agricultural sector as a result of climate change is clearly yet to evolve to a point where some moderately reliable results are available.

One of the most intriguing comments in the Report appears in the concluding section of the penultimate chapter, titled "Risk Assessment of Climate Change: An Overview" (Ch. 7, pp. 137–38). This section on risk management, which gives the impression of being tacked on at the end, takes special care to argue that one viable strategy for decision-making under uncertainty is to postpone action till more information is available, since to take action now would be to incur irreversible costs that may well be avoided and may not be even the best investment to undertake for adaptation. This argument appears to be complementary to the overall trend of results emerging from general equilibrium models or partial equilibrium models of the economic impact of climate change.[11] Such estimates have been widely criticised because they tend sharply to underweigh the economic losses due to climate change, on account of the discount rate that is applied to future costs. On the other hand, immediate mitigation costs tend to be higher, precisely because they are undertaken earlier.

[11] The seminal work in the application of general equilibrium models to the economics of climate change is due to William Nordhaus. See, for instance, Nordhaus (1996). For a review of the problems of general equilibrium models of the economics of climate change, see Ackerman (2007).

It is then unsurprising that general equilibrium model arguments tend to suggest that strong action to mitigate climate change can be postponed until renewable energy or carbon-capture technologies are sufficiently developed. Such estimates, especially from mainstream economists from the United States, have been perceived as underlying the US position on delaying climate action and have drawn severe criticism from many commentators on climate policies.

The Report presents a serious scientific account of the impact of climate change on agriculture in a country that is a global leader in agricultural production. Nevertheless, it is difficult to argue that the serious deficiencies in the Report in dealing with the specifics of adaptation and the economics of climate change merely reflect the state of the art of its subject matter. Although the Report follows a method of presentation similar to IPCC Reports, which only review published literature on the various aspects of climate change, one cannot ignore the fact that its terms of reference call for a more decisive, critical evaluation of climate adaptation and its economic consequences. Nevertheless, in the context of climate change politics in the United States, where farmers' lobbies have consistently ranged themselves with groups that deny climate change altogether, the Report constitutes an important positive contribution.[12]

**Keywords**: Climate change, global warming, US agriculture, USDA, farming in the United States

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## *References*

Ackerman, F (2007), "Debating Climate Economics: The Stern Review and Its Critics, Report to Friends of the Earth, England, Wales and Northern Ireland," available at http://sei-us.org/Publications_PDF/SEI-FOE-DebatingClimateEcon-07.pdf, viewed on 5 June 2013.

CCSP (Climate Change Science Programme) (2008), *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity: A Report by the U. S. Climate Change Science Program and the Subcommittee on Global Change Research*, by Backlund, P., *et al.*, United States Environmental Protection Agency, Washington, D. C., pp. 362.

FAOSTAT, available at http://faostat.fao.org, viewed on 5 June 2013.

IPCC (Intergovernmental Panel on Climate Change) (2012), *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*, Field *et al.* (eds.),

[12] See, for instance, news reports at http://grist.org/food/can-usdas-climate-reality-message-take-root-with-denialist-farmers/and http://grist.org/article/tough-spot-for-farmers-adapting-to-change-you-cant-believe-in/, viewed on 6 June 2013.

Cambridge University Press, Cambridge and New York; available at http://ipcc-wg2.gov/SREX, viewed on 21 June 2013.

Lobell, David B. (2011), "Climate Trends and Global Crop Production since 1980," *Science*, no. 333, pp. 616–20.

Nordhaus, William D., and Yang, Zili (1996), "A Regional Dynamic General-Equilibrium Model of Alternative Climate-Change Strategies," *American Economic Review*, vol. 86, no. 4, September, pp. 741–65.

OECD–FAO (2011), *OECD–FAO Agricultural Outlook 2011–2020*, OECD Publishing and FAO; available at http://dx.doi.org/10.1787/agr_outlook-2011-en, viewed on 5 June 2013.