Agriculture in the IPCC Assessment Reports

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Here we describe how the treatment of agriculture has evolved over the course of the IPCC, as tracked across the five Assessment Reports (ARs).

From the First (in 1990) to the Fifth (in 2013/14) IPCC Assessment Report, both the level of detail and quantification of the impacts and adaptation, and mitigation potential of the agriculture sector has grown enormously, reflecting the almost exponential increase in available literature on the topic. For example, using the search terms '(agriculture or ghg or greenhouse gas) and climate and mitigation' for mitigation, '(agriculture or ghg or greenhouse gas) and climate and (adaptation or impact)' for adaptation and impacts, about 600 and 1800 papers were published on the Web of Knowledge (WoK) database in 2016, compared with 0 and 7 papers in 1990, for mitigation and impacts/adaptation, respectively.

Impacts of climate change on agriculture and adaptation options

The first IPCC Assessment Report (FAR), published in 1990 pre -dated the UN Framework Convention on Climate Change by four years. On its initiation four years later the Convention stated that greenhouse gas concentrations should be stabilised so "such a level should be achieved within a time -frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner." Thus, food security was specifically identified as one of the key elements to be protected from climate change. The focus on food security was also strongly reflected in the COP21 Paris Agreement of 2015, both in relation to mitigation and adaptation (Wollenberg et al. 2016).

Over the five Assessment Reports (AR) from 1990 (FAR) to the last (AR5) in 2013-14, agriculture has featured in a number of guises; having a separate chapter in the second assessment report (SAR) and AR5 but in the other reports it was bound in with ecosystems (third assessment report, TAR) and forestry (TAR and AR4). Only in AR5 did the relevant chapter ('Food Security and Food Production Systems') directly address the UNFCCC food security focus. Fisheries, a key source of nutrition in many regions, was integrated with agriculture in AR4 and AR5 whereas previously it had been separated, with a dedicated chapter in the SAR markedly increasing the literature coverage (Figure 1A). Regional agricultural coverage has been shared since the SAR via regional chapters (Figure 1A). The comprehensiveness of coverage of climate and CO_2 impacts on crops has increased markedly (Figure 1A) whereas given their global significance, livestock have been significantly under- represented since the SAR (e.g. Rivera-Ferre et al. 2016). Over time there has been a shift in focus from just climate and atmospheric impacts on agriculture to include more adaptation; there were no adaptation studies in the FAR, increasing to 18% of studies in AR5 (Figure 1A). AR5 provided the first assessment of the overall effectiveness of climate adaptations for crops (Challinor et al. 2014).

Key literature used over the course of the 5 ARs includes 1745 publications synthesised, assessed and referenced. Approximately 75% of these came from journals with peer review, reports from international organisations or government bodies. More than 840 modelling or experimental cases have been included in the five AR agricultural analyses of which about 40% of experiments or model analyses have included adaptation and/or elevated CO_2 as treatments.

There is a strong degree of consistency in results across the five Reports. In relation to climate impacts on crop yields, whilst the FAR clearly had fewer studies than the other four, in all cases median and mean projections are close to each other. There is no discernible effect on the variation in model projections from the number of studies performed. The grand mean of the five ARs (+ 0.81%) and the overall median (-0.75%) shows little change in food production for a range of scenarios of climate change, location, crops and levels of adaptation. This should be of great concern given the projected rise in human population to around 9 billion by 2050 for which a conservative estimate is a required 60% increase in food production (Alexandratos & Bruinsma, 2012), in the absence of other ways to enhance food security (Porter et al. 2014) .

Based on the more than 400 papers that have cited the AR5 food security chapter (Porter et al., 2014) in AR5, post-AR5 research in food security has focussed on: global and regional health and climate change; climate smart-agriculture; climate change and poverty; adaptation research at farming system level; closing yield gaps; decoupling GHG emissions from agricultural production; food supply shocks; food security and SDGs; food safety and climate change; cost of food and climate change; diversified food sources; food shortages and conflicts; traits for genotypic plant adaptation; FACE experiments on rice; nutrition in Africa; agriculture in COP21; novel food products for nutrition; climate change and cattle; aquaculture; increasing use of time -of - emergence techniques for crops. In our opinion – key points missing from the list, or under-represented, are:

1. Regional and global assessments of food nutrition and security under different RCPs including when critical changes may happen under specific scenarios.
2. Adaptation implementation and effectiveness especially in relation to climate extremes
3. Climate change impacts and adaptation effects on net GHG budgets especially soil C levels
4. Relative lack of climate impact and adaptation studies on fruit and vegetables and on pests, diseases and weeds.

Climate change mitigation in agriculture

While the number of pages dedicated to agricultural mitigation has increased over the five ARs; from 11 to 53, when comparing the proportion of global emissions arising from agriculture with the percentage of pages dedicated to agriculture in each volume, agricultural mitigation remains under-represented (Figure 2).

The emissions sources considered in the agriculture sector have remained similar, despite systems boundaries being drawn differently in different ARs. All ARs consider rice cultivation, ruminant animals, and biomass burning for methane emissions, use of nitrogen fertilizers for nitrous oxide emissions and land clearing and biomass burning for carbon dioxide, methane and nitrous oxide emissions. In the SAR, energy use in agriculture was included and emissions attributed to agriculture, but not reported in the agriculture sector (e.g. agriculture related land use change) were included. The TAR had a more prominent focus on energy and this included a stronger emphasis on energy use in agriculture. In AR4, land use change was excluded in sectoral emissions estimates as there was a separate chapter on forestry and land use change, and energy use in agriculture and bioenergy were reported separately. In AR5, agriculture was considered in the same chapter with forestry, land use change and bioenergy production, but emissions could be disaggregated. Over time, the organisation of emissions has come to align with the structure of the IPCC GHG Inventories.

In terms of the mitigation options considered, reduction of methane from rice production, enteric fermentation, manure management and biomass burning, and reduction of nitrous oxide from reduced / better use of fertilizers have featured since the FAR, as has increasing carbon sinks in agricultural soils. Bioenergy to displace fossil fuels has featured since the SAR, though it has not been treated as an agricultural mitigation option since the SAR, because the savings occur in the energy generation sector. Reduced use of energy in agriculture featured strongly in the SAR and TAR reports, but since the savings are attributed to other sectors (e.g. buildings, transport), this featured less strongly in AR4 and AR5.

Supply-side measures for agricultural climate mitigation have dominated the ARs. Among demand - side measures, reduced waste was mentioned for the first time in the TAR as was the potential for dietary change from greenhouse gas intensive products like meat toward lower impact alternatives. The opportunities for behavioural change of farmers to reduce their net GHG profiles was also discussed for the first time in the TAR. There was little consideration of demand -side measures in AR4, but in AR5, the first comprehensive global analyses of the GHG benefits of demand-side measures were reported.

Perhaps the most important change between the 1st and 5thAR is the degree of quantification of mitigation potential in agriculture. In the FAR, mitigation options were described in general terms and mitigation potential was not quantified. In the SAR, estimates of global technical mitigation potentials were made, with an emphasis on soil carbon sequestration and bioenergy production, though methane and nitrous oxide potentials were also estimated (as a percentage reduction on current emissions). Economic feasibility was discussed for the first time. By the TAR, a global aggregate mitigation potential was given, and the broad economics had been assessed, with most of the mitigation potential reported to be realisable at carbon prices 0-100 US$/tCeq. For AR4 and AR5, global technical as well as economic mitigation potentials were given at three carbon prices: 20, 50 and 100 US$/t$CO_2$-eq.

Analytical methods have also changed: in the 1st and 2nd ARs the mitigation potentials were assessed bottom-up, i.e. practice-by-practice of the land area/ livestock numbers available, and in the TAR this was replaced largely by top-down assessment of integrated assessment models (IAMs). In AR4 and AR5 both bottom-up and top-down estimates were included. IAMs have the advantage that they can consider mitigation options across sectors and select least cost options/ pathways for mitigation, which bottom-up approaches cannot. Their disadvantage, though, is the limited number of agricultural options that they include, which are mostly confined to non-CO_2 greenhouse gases. Bottom-up approaches, on the other hand, have rich detail of the agricultural practices available, but are unable to consider mitigation across sectors, so estimates of economic potential are more uncertain. Global mitigation potentials from the 1st to 5th ARs are shown in Figure 2.

While quantification has improved, wide ranges for estimated mitigation potential remain, since there are many sources of variation which all contribute to the overall uncertainty (e.g. in per-area/ per-animal estimates of potential for various practices in different climate regions, in areas/ animal numbers applicable, in poor activity data to establish baseline levels of practice; Smith et al. 2014). While uncertainty is, therefore, difficult to quantify numerically, it has been possible since AR4 to attach uncertainty language statements to most components of the mitigation budget, with the statements on total supply-side mitigation ranges assessed as “medium evidence; medium agreement”, while reported demand-side ranges were assessed as “limited evidence; medium agreement” in AR5. The main changes in the treatment of mitigation from the 1st to 5th AR are shown schematically in Figure 1B.

Conclusions

Given the central role of food security and land-based mitigation in the frameworks and protocols that commenced with the UNFCCC in 1990 and culminated in the COP21 agreement in 2015, we think it is fair to state that agriculture, food security impacts, adaptation and mitigation have had inconsistent histories in IPCC ARs. In most ARs, food security has been equated with the production of agricultural crops, largely omitting fisheries and under-representing livestock, foods important to human nutrition to the human diet and the non-production social and economic factors that underpin food security. We are heartened by the evidence post-AR5 that these issues seem to be occupying the minds and interests of food security researchers globally. A second conclusion must be that the studies upon which IPCC authors write their syntheses and evaluation reports are hugely dominated by modelling studies to the detriment of experimental and observational studies of climate and agriculture. Compared with running large scale experimental facilities over representative periods of time – modelling is inexpensive and thus favoured by a philosophy of ‘more data per dollar’ but not necessarily ‘more knowledge per dollar’ . In the mitigation chapters, the consideration of the land sectors (agriculture, land use change, forestry and bioenergy) either together or separately has varied with each AR. Treating the land resource consistently is important, and allows for a more consistent and integrated assessment.

Looking forward to the IPCC AR6 cycle (and the Special Report on Climate Change and Land), key emerging issues are likely to be: a) Trade-offs between the use of land for food production and use of land for greenhouse gas removal (such as through reforestation or bioenergy with carbon capture and storage (Smith et al., 2013; Smith et al., 2016); b) The contribution that dietary change and waste reduction could play to reducing pressure on land (Bajželj et al., 2014); c) The co-delivery of global nutrition security, climate change mitigation and adaptation, and the UN sustainable development goals (Tilman & Clark, 2014). Examining the impacts, adaptation and mitigation opportunities related to agriculture and food security, and the land more broadly, remains a challenging issue due to the complexity of the sectors involved, but given the importance of food and agriculture for climate change, and their central role in human existence, it is a challenge that must be met.

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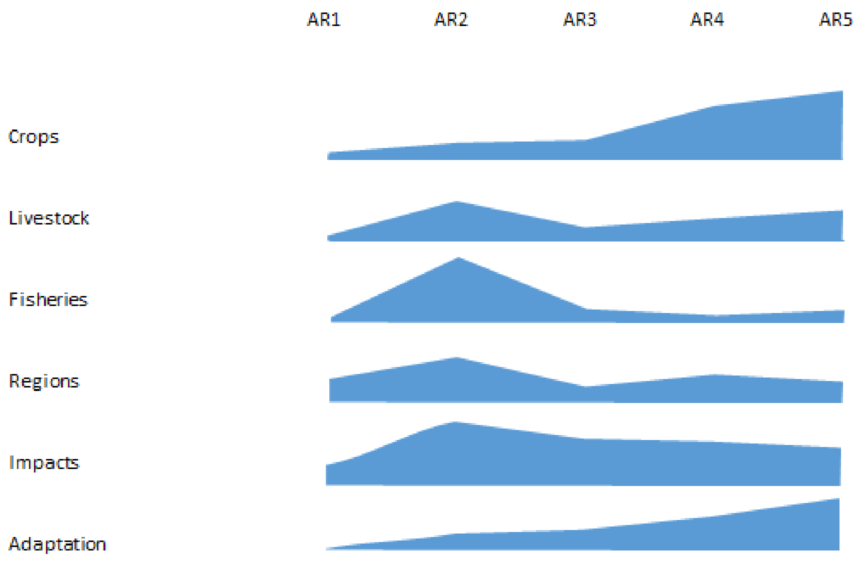
Figure captions

Figure 1A. Schematic representations of the amount of coverage of topics covered in IPCC AR chapters dealing with agriculture and food security impacts and adaptation and projected median and mean % changes in yield for all crops, all experiments and all modelling studies for the 1st to 5th AR and the range of the means. Data for AR4 were all single model means – thus no range in the separate estimates.

Figure 1B. Schematic representations of the amount of coverage of topics covered in IPCC AR chapters dealing with agricultural mitigation showing space dedicated to agricultural mitigation in each AR.

Figure 1A



Assessment Report		Median change	Mean change	Mean model range
1	n = 34	12.3	10.1	13.4
2	n = 99	-4.8	-6.2	41.2
3	n = 97	-7.3	-6.9	22.7
4	n = 434	2.5	4.8	-
5	n = 181	-6.5	-5.8	19.9

Figure 1B

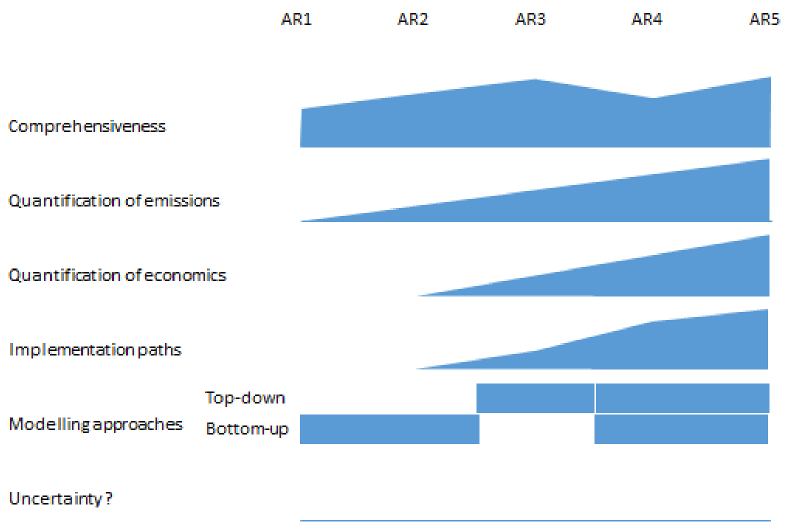


Figure 1A. Schematic representations of the amount of coverage of topics covered in IPCC AR chapters dealing with agriculture and food security impacts and adaptation and projected median and mean % changes in yield for all crops, all experiments and all modelling studies for AR1-AR5 and the range of the means. Data for AR4 were all single model means – thus no range in the separate estimates. Figure 1B. Schematic representations of the amount of coverage of topics covered in IPCC AR chapters dealing with agricultural mitigation showing space dedicated to agricultural mitigation in AR1 to AR5.

Figure 2. Estimates of total global mitigation potential in agriculture in each AR (after conversion to common units), showing technical potentials, and economic potentials at 100, 50 and 20 US$/t$CO_2$e, where given. The technical potential of demand-side measures are also shown for AR5. Note that SAR values have no target year, TAR values are for 2020, AR4 values are for 2030 and AR5 values are for 2050. For SAR and AR4, additional mitigation potential for fossil fuel offsets from bioenergy were reported (1467 -5501 MtCO_2e/yr in the SAR and 560- 2320 MtCO_2e/yr in AR4), and in AR4, additional mitigation through improved energy efficiency in agriculture was reported to be 770 Mt CO_2e/yr, but since the emissions reductions from bioenergy and energy efficiency improvement are accounted for in other sectors, these additional mitigation potentials are not included in Figure 2. Inset shows agricultural emissions as a percentage of total anthropogenic emissions in each AR (green) and pages dedicated to agricultural mitigation as a percentage of the relevant volume (red) in each AR.