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# Food Systems and Climate Engineering: A Plate Full of Risks or Promises?

In 2030, Joe's lunch plate may have interesting novelties like the ClimateFighter® curry meal. Its rice comes from special genetically modified (GM) high-albedo crops that also emit less methane than traditional crops. Vegetables are grown in a farm that is certified for actively promoting soil carbon sequestration. Energy efficient mycoprotein has replaced the meat. While eating this climate-friendly meal, Joe hears from the news that the global agreement has been made on starting aerosol-based climate engineering all over the world, but food justice movements protest against it and require governments to subsidize ClimateFighter® varieties and traditional mitigation policies on agriculture instead.

Whether this fictive story realizes itself or not, important and difficult questions arise from interactions between climate engineering, climate mitigation, and food production and consumption. On the one hand, global warming makes the objectives of food justice – securing the right to food and ensuring that food system activities, such as production and retail, are fair in their distribution of benefits and burdens – even more difficult to reach. On the other hand, there are ways in which "next generation food systems" could contribute to mitigating emissions and engineering the climate.

This chapter analyses the ethical challenges, risks, and opportunities that result from the complex relations between food systems and climate engineering. As a normative point of departure, we take it there is an obligation to secure sufficient (and sustainable) food production that meets the human nutritional needs and is culturally acceptable. The article has a conjectural tone since engineering the climate (with agricultural means or otherwise) still lies some way off in the future. However, the critical task of environmental philosophy is also to consider possibilities in advance, even if they may never be realized.

Our comparative approach aims to answer the following questions: Are there ways that food production could contribute to, or be tied into, climate engineering? Conversely, how does climate engineering affect food systems? Moreover, we study whether climate engineering might create adverse effects or serious risks that hamper promoting food justice and, hence, justice in climate matters as well – or whether climate engineering could help promote food justice.[i] For the purposes of this article, we distinguish between agricultural and non-agricultural geoengineering. The former refers to climate engineering that is based on the use of plants, animals and microbes in food production; the latter denotes other techniques with no food-related intentions. 'Climate engineering' without qualifications refers to the whole field of climate modification, unless the context clearly indicates otherwise.

## The Background: Food Systems and Climate Policies

Feeding people will be a challenging task in the future. According to the IPCC *Synthesis Report*, "Global temperature increases of ~4°C or more above late 20th century levels, combined with increasing food demand, would pose large risks to food security globally (high confidence)" (IPCC 2014a, 13). Climate change will affect the production and transportation of food, increasing the risks of malnutrition and famines, as well as the inequalities with regard to food production, rural livelihoods, and access to food. Meanwhile, food systems are a significant source of greenhouse gases (GHGs): food accounts for 25-30% of total GHG emissions when the related energy use and land use changes are taken into account (Garnett 2011; IPCC 2014b). The most debated singular source is the livestock sector. It contributes 18% to overall anthropogenic GHG emissions and is responsible for more than 50% of the emissions related to land use, forestry, and agriculture (Steinfeld et al. 2006). The emissions from rice farming are also remarkable and rice is responsible for almost 20% of anthropogenic methane emissions (Chen and Prinn 2006). Emissions are also produced in the transportation, processing, packaging, retailing, and consumption of food, not to mention food waste itself.

There is significant potential for emission reductions in the global food system (IPCC 2014b), and it is very unlikely that overall GHG emissions could be sufficiently reduced without addressing food sector. In other words, changes in the food system probably have to be an essential part of any emissions mitigation strategy. What this implies is by no means self-evident. Many commonsense ideas about food related emissions are misplaced: neither organic nor local food are unequivocally superior choices, packaging matters relatively little after all, and transportation from store to home counts usually more than all earlier transportation phases (Foster et al. 2006). Emission reductions in the food system then require particular policies. This raises questions we are going to address: could farming be harnessed to advance emission mitigation or climate engineering?

In our discussion, the concepts of food systems and food justice play key roles. A food system is a network that defines and structures the production and consumption of food. Food systems consist of food system activities ("from seed to fork"), actors (from industry to political institutions), and drivers such as socio-political factors and global environmental change that together shape these activities (Ericksen 2008). There are global, regional, and local food systems: borders cannot be strictly drawn and systems overlap. International trade agreements, for example, affect food systems on all levels. Therefore, the concept of the food system is used in a plural form.

The notion of food justice is used here broadly. First, food justice is a normative criterion for evaluating food systems ethically and politically. Its crux is the requirement to satisfy the food-related needs of human beings[ii] now and in the future. Second, in a sociological analysis, Gottlieb and Joshi (2013, 4) characterize food justice as something that aims at "ensuring that the benefits and risks of where, what, and how food is grown and produced, transported and distributed, and accessed and eaten are shared fairly". Accordingly, among the persistent issues of the food justice debate are working conditions, gender inequalities, and agricultural trade policies. Therefore, food justice is a framework that aims to expose the existing power relations and assess their legitimacy in food system activities (Alkon and Agyeman 2011). Moreover, food justice has also been associated with non-distributional issues of justice such as representation and recognition (**see Hourdequin chapter in this book**). The ethics and politics of food are not insulated from wider social issues.

As we see it, climate change and food issues are inseparable: when the anthropogenic climate change contradicts the requirements of food justice, it harms people as well. Similarly, climate engineering has implications for food justice, and several considerations must be born in mind in recognizing the linkages between the two types of harms: changing the climate constitutes an unjust action that reduces the possibilities to maintain food system activities in a way that promotes food security and fair conditions for farmers and labour. It will turn out that some themes discussed within the “agricultural geoengineering vs. food justice” framing are also important for the “mitigation vs. food justice” framing, such as bioenergy versus food production and issues related to GM crops.

## From Farm to Air: Incorporating Geoengineering into Agriculture

Food systems have a dual role with regard to climate change: although they are major greenhouse gas emitters, agriculture also provides a significant carbon sink, both in the short and long term. This is evident in the seasonal variation of $CO_2$ concentration in the atmosphere famously detected in the Mauna Loa observatory (the Keeling Curve graph), which shows that during the summer of the northern hemisphere terrestrial plants promote considerable carbon uptake through photosynthesis. Some of this carbon uptake is stored in the soil over long periods. Through these mechanisms, carbon is constantly being captured and removed from the atmosphere. The duration of these sinks depends on the future use of the plants and land. Vegetation can also reflect radiation away from earth[iii] and this albedo effect can possibly be utilized to decrease regional temperatures (Singarayer et al. 2012).

The deliberate utilization of these techniques to affect the atmosphere’s carbon concentration is called bio-geoengineering and, when linked with food production, could be called agricultural geoengineering, though not all bio-geoengineering is agricultural in the sense of being intended to produce food (e.g. tree planting and farming non-food plants like cotton and tobacco). In what follows, we evaluate two forms of agricultural geoengineering, one related to SRM and another to CDR. The question on which we focus is whether their utilization (either as alternatives or as complements to non-agricultural climate engineering) would promote food and climate justice.

## Bio-geoengineering Through the Albedo Effect

The reflectivity (albedo) of plant material varies greatly between different plant species, and even between different strains of the same species. There is a growing interest in utilizing this phenomenon, and some researchers find crop albedo geoengineering a promising technique for decreasing regional or local temperatures. Singarayer et al. (2012) estimate that by choosing strains (and in some areas by changing cultivated species) with higher reflectivity, it would be possible achieve ca. 1–1.6 ºC regional cooling in Europe in summer, while in South Asia the cooling effect is smaller and occurs during winter. Further, there might be positive impacts on food productivity in particular cropland regions due to decreased heat stress, though these effects are estimated to remain regional.

From the viewpoint of just climate policies, albedo geoengineering would have several benefits as a climate engineering technique. It has low risks (unlike many other SRM methods) and low implementation costs, as the required infrastructure is ready in the farms. It is estimated, with some caveats we will discuss later, to have no significant negative effect on productivity and food security, and there might be beneficial precipitation increases in certain areas such as Europe (although this varies by region) (Singarayer et al. 2012; Ridgwell et al. 2009). Regional cooling might alleviate other problems such as heat wave related diseases or mortality, hence promoting justice in climate matters in a more general sense. However, there are three other concerns for food justice: 1) issues of creation and distribution of varieties (including availability, intellectual property rights, and genetic modification); 2) threats to agricultural diversity and biodiversity; and 3) undiscovered threats to food security.

## Challenges with Plant Modification Approaches

Before the deployment of albedo based geoengineering can be carried out, crop varieties would have to be developed that have the desired qualities, are safe for human consumption, and are available for large-scale use. These novel varieties could result from either traditional plant breeding, whereby their use might not face significant legal or political obstacles, or from genetic engineering. In this latter case there are various regulatory protocols to be met and further ethical issues that could arise. The acceptability of genetically modified varieties in food production is a widely discussed and contested topic (especially in Europe). Even though an increasing amount of agriculture relies on GM varieties, the opposition to them is staunch. The creation of plant varieties for agricultural geoengineering through GM also raises ethical issues characteristic of the ‘traditional’ GM food discussions, such as health risks related to GM products, the right of the consumer to know, and the public interest to protect the food system from GM products.

Let us assume here that GM varieties gain legal and social acceptance and that they are safe. Even then, further obstacles to their use might emerge from geopolitics, as states might be reluctant to engage with the technology transfer and want to retain their hold on strategic varieties. Moreover, there are powerful private interests involved in the form of intellectual property rights. Although the rights holders may not always benefit from preventing anyone from using GM varieties, conflicts of interests are commonplace. Consider the eagerly anticipated Golden Rice. It relied on many inventions that were protected by intellectual property rights but the rights holders showed goodwill and allowed for their subsistence use (Potrykus 2001). Golden Rice developers have also established the idea of “Humanitarian Use License” that provides “free access for those who need it.”[iv] However, due to reasons that vary from regulative issues to objections by environmental movements, Golden Rice has not reached fields despite its availability since 2000. Acceptance from farmers is vital. What this example points out is that even though suitable varieties could become available, their use might face serious social, legal and political hindrances[v].

Agricultural geoengineering based on plant modification, whether genetic or not, also constitutes a biodiversity related risk of “bio-perversity”. Adopted from forestry research, bio-perversity refers to situations where climate-motivated reforestation policies have decreased diversity, because policy evaluations have considered the ecological consequences of reforestation policies too narrowly (Lindenmayer et al. 2012). We find this risk conceivable in agriculture if efficient new SRM varieties are promoted extensively. This can be in conflict with farmers’ sovereignty, if the alternatives are circumscribed and the farmers are compelled to choose a certain crop variety against their own desires. As we argued earlier, SRM varieties should be broadly available; yet, their use should not be too extensive (this however reduces their effectiveness at a global level), and the opportunities for the choice in farming should be protected.

Another diversity-related worry concerns the effects of SRM-type agricultural geoengineering on landscapes. A rural landscape, shaped by agricultural activities, is highly valued in many parts of the world and considered as an important part of traditional biodiversity (even though there are huge areas of monocultures that have mainly economic, rather than cultural, value.) Deploying agricultural SRM might affect these landscapes. Although it is too early to say whether people would find this positive or negative, this dimension should not be neglected.

Problems of another kind would arise if new SRM strains were efficient in terms of their albedo effect but had some other unpredicted and undesired properties. Although Singarayer et al. (2012) do not consider albedo engineering to significantly risk food security, they acknowledge that there are uncertainties concerning the actual operational yields and disease or drought resistance of albedo crops. Were such trade-offs realized, it would invoke problems similar to the "biofuels vs. food production dilemma", although with less mutually exclusive alternatives. Is it justifiable to use arable land for climate crops that produce less food but more climate benefits? If it is, to what extent? This problem is a very conjectural one, however, unless future research suggests that there are trade-offs between albedo and other agriculturally important properties of the plants.

## Soil Carbon Sequestration and Agricultural Production

Much attention has recently been paid on soil carbon sequestration. Sequestration methods within food production include field management (such as reduced tillage, erosion control, and cover crops) and biochar (biomass based charcoal used as soil amendment). BECCS or bio-energy with carbon capture and storage is a sequestration method in which energy crops are combined with carbon capture and storage, producing negative emissions (IPCC 2014b). BECCS is admittedly non-agricultural bio-geoengineering (as it does not involve food-related intentions), but we discuss it here because of its indirect yet important relation with food production through the utilization of arable land.

The first thirty centimeters of soil contains three times as much carbon as all of the global ground vegetation (Powlson et al. 2011). Some estimate that carbon sequestration could therefore have huge potential, removing up to 50 ppm carbon equivalent from the atmosphere in the next century (Lal 2013). Yet, others are more cautious about the significance of this method and warn that the most optimistic calculations have been too simplified (Powlson et al. 2011). Despite disagreement on the effectiveness, soil sequestration is considered to be a ‘no regrets’ policy. Risks are low, and “any measure that increases [soil carbon] content is likely to have beneficial impacts on soil properties and functioning” (Powlson et al. 2011, 53). Biochar is broadly agreed to improve soil fertility in addition to its carbon sequestering effects (Conte 2014). Improved soil functioning in turn often affects food production positively and hence improves long-term food security.

Some might argue that soil carbon sequestration is not a climate engineering method at all. On the other hand, a technique that adds biomass to the soils and makes possible the revegetation of degraded land while at the same time sequestering carbon seems like a highly desirable practice, whether or not you choose to call it climate engineering. Other revegetation activities such as large-scale afforestation and reforestation usually are considered a CDR technique (Preston 2012, 2), which speaks in favor of also counting more permanent soil carbon enhancements as a CDR technique. A more detailed article on the distinctions between mitigation, adaptation and climate engineering activities (Boucher et al. 2014, 32) proposes categorizing these kinds of techniques as territorial or trans-territorial removal of atmospheric $CO_2$ and other long-lived greenhouse gases to distinguish them from emission reduction practices. That being said, how does this method look like from the climate and food justice viewpoint?

By definition, ‘no regrets’ policies are expected to be relatively safe and have predictable consequences. Furthermore, especially plant based agricultural geoengineering practices are easy to cancel due to their annual renewal. With view to harms, sequestration within food production seems to be a solution that at least does not raise any major doubts of injustice and, moreover, potentially meets the need for negative emissions. One objection that needs consideration, however, concerns the efficacy and costs of these actions. What is the accepted additional price for the sequestered carbon, if the permanency of sequestration is uncertain (and depends not only on natural factors but on future policies and the actions of future farmers)? Another question is, who should pay the costs of these actions in the developing countries: those most responsible for climate change (the global North) or those benefiting from the actions (the global South)?

In contrast, BECCS appears unviable in relation to food justice. It inherits the ethical dilemmas of the “energy vs. food” debate. In the context of scarce fertile arable land, reserving it for energy crops to a significant extent is likely to risk food security and, accordingly, impede food justice. There is a possible exception to this: sourcing biomass from agricultural waste and side streams instead of dedicated energy crops might make BECCS a justifiable addition to the policy toolbox.

From the food justice viewpoint, it is arguable that compared with SRM related agricultural geoengineering, CDR through soil management is indeed more favourable and promotes food justice better. Lal (2013) has argued that soil carbon sequestration also addresses food security in developing countries by increasing their agricultural productivity (in a sustainable way). If this argument is sound, there are chances that at least in some cases, carbon soil sequestration is a win-win solution with important co-benefits: enabling climate engineering in a way that at the same time promotes food justice.

## Non-agricultural Climate Engineering and Food Systems: Harms or Synergies?

Non-agricultural climate engineering can have consequences for all aspects of food systems. Neither agriculture itself, nor food processing, transportation, marketing and consumption are safe from the different hydrometeorological changes and side effects associated with climate engineering. Arising from this, we next address whether non-agricultural climate engineering is acceptable from the viewpoint of food justice. When it is compared with emission mitigation through more sustainable food systems, which alternative is likely to promote food justice most?

**Kommentoinut [Preston, 1]:** Since this is hypothetical, it is probably not possible to be sure at present.

### Risks and Uncertainties

Both the estimated effects of and uncertainties related to non-agricultural climate engineering are relevant when these policies are to be evaluated by the food justice approach. In addition, it is important to consider how the expected benefits and harms are distributed among different communities. Climate engineering is here compared with more traditional mitigation policies in food systems. Which issues of justice arise when these two alternatives are compared and do they make any difference for food justice?

The estimates for mitigation potential (excluding agricultural geoengineering) in food systems vary enormously. Agricultural production has the potential for 7.2-11 $GtCO_2eq$/year reductions by 2030 (through cropland management and restoration of organic soils) and the demand side potential estimates vary between 0.76 to 8.6 $GtCO_2eq$/year (IPCC 2014b) (through reducing food waste and changing diets). Given that the global emissions were 49 $GtCO_2eq$ in 2010 (IPCC 2014b), ‘greening the food systems’ significantly contributes to GHG mitigation policies.

Some mitigation options in food systems are problematic in that they can impede food justice. These include policies that threaten food production or increase overall food prices globally or locally, such as the promotion of biofuel crops, and regulations that might violate the food sovereignty of local communities by, for example, restricting their freedom to define their own food ways. It could also be argued that the individual right to control one’s own food and nutrition practices would be to some extent violated if the policies set *de facto* constraints on the opportunities to consume climate burdening food items. However, the food justice discourse itself strongly endorses environmental sustainability and acknowledges (at least to some extent) that food sovereignty should be exercised within ecologically sound limits (see Gottlieb and Joshi 2013, 226; Holt-Giménez 2011), so we suggest at least the majority of GHG mitigation in food systems is compatible with food justice. These mitigation options include but are not limited to more sustainable cropland management practices, the restoration of organic soils, and reducing food waste.

Non-agricultural climate engineering strategies differ greatly in terms of their effectiveness, predictability, and reversibility. CDR methods are considered generally safer, more predictable and more safely reversible, but also significantly less efficient, in comparison with SRM. Keller et al. (2014) contend that CDR methods are unable to prevent warming from continuing well above two degrees and are predicted to have a modest impact at best. Both CDR and emission mitigation in food systems are then partial solutions.

To our knowledge, non-agricultural CDR techniques such as artificial trees usually have no significant direct effect on food systems overall. They would reduce $CO_2$ (hence having a slightly negative effect on yields) but also reduce temperature stress (hence having a positive effect on yields) (cf. Pongratz et al. 2012). The indirect effects of CDR in alleviating or slowing down climate change can contribute to promoting food justice by two mechanisms: 1) allowing more time for adaptation, and 2) reducing yield losses in the long run (by diminishing the impacts of climate change). The total contribution of these techniques is then likely to be slightly positive in terms of food justice.

While SRM has greater potential to prevent warming, it also carries significantly higher risks. A few model-based predictions have been made on the effects of SRM strategies on agriculture. Decreases in precipitation, possibly up to 9% in a global scale and even more in particular tropical regions (Keller et al. 2014, 8), might threaten food production. This would violate food justice by degrading food security and by increasing inequalities between communities, depending on their adaptive capacity. On the other hand, Keith (2013, 9–10) asserts that moderate SRM with sulfates would actually reduce crop losses in the hottest areas (in comparison with the same GHG levels but no SRM). Pongratz et al. (2012) propose that SRM has generally positive yet limited effect on yields, but some regions may face undesired impacts and yield losses that threaten their local food security. Moreover, the authors remark that “SRM poses substantial anticipated and unanticipated risks by interfering with complex systems that are not fully understood” (Pongratz et al. 2012, 104). This makes them conclude that the potential of SRM to reduce the overall risks of climate change on food security is not established and that emission mitigation is still the safest climate policy option with regard to global food security.

Another question is whether uncertainties related to SRM can be decreased. Robock et al. (2010) argue that even testing aerosol-based SRM would require full-scale implementation that could seriously disrupt food production and affect the food supplies of more than 2 billion people due to changes in precipitation. Risks related to precipitation changes caused by SRM are serious. It is possible that some future plant varieties can handle drought and variations in the timing of precipitation; drought resistant plants are already being studied (Ling and Jarvis 2015). Some proponents of SRM have also asserted that these risks are partly exaggerated and misunderstood, at least if SRM is deployed to a moderate extent only (Keith 2013).

An argument for effective, full-extent SRM is that it would make mitigation in food systems unnecessary, hence being the best option for securing food sovereignty and consumer autonomy. This proposal however is problematic because climate engineering cannot tackle other environmental problems of food production (such as habitat loss, soil degradation and water eutrophication), and the need to restrict or change environmentally harmful food activities is likely to remain. Therefore, we contend that full-scale SRM at least (such as extensive stratospheric sulphate aerosol injection) is likely to have too substantial risks and relatively narrow benefits from the food justice viewpoint and in comparison with other available strategies. Yet, it is possible that future research shows these risks to be controllable and rather insignificant, which would in turn require changes in these ethical considerations on SRM and food justice.

Non-agricultural engineering of the climate could, in the worst case, function as a trigger for an unpredictable global scale humanitarian crisis. Such a crisis could come about if the deployment of full-scale climate engineering turned out to disrupt the food production of 2 billion people, realizing a risk discussed by Robock et al. (2010). Such a disruption would increase food prices and cause food insecurity, which would likely inflict (food) refugee floods and political unrest around the world due to scarce food supplies and increased food prices. This 'trigger risk' provides strong grounds for following the precautionary principle with regard to deploying the riskiest SRM methods in a large scale. Consequently, especially techniques that are hard to reverse are barely acceptable from the viewpoint of food justice, if there are alternative mitigation or engineering strategies that are together sufficiently effective.

## Conclusion

Although the importance of food might not always be recognized in climate policies, there are no reasons for overlooking it. Agricultural climate engineering provides a good example of how emission mitigation and climate engineering can be combined (**cf. Fragniere-Gardiner in this book**), though it is unclear whether global cropland area is sufficient to provide effective global mitigation. On the other hand, certain climate engineering techniques can have significant impacts on global food security and food justice. As we see it, this creates a moral obligation to consider the effects of climate engineering on food systems with open eyes.

Agricultural activities can contribute to climate engineering mainly by SRM geoengineering and enhanced soil carbon sequestration methods. Non-agricultural CDR and SRM techniques vary significantly in their effects on food systems. Evaluating these alternatives with regard to food justice requires considering both how these techniques promote or impede food justice, and their effectiveness in decreasing the harmful effects of climate change to food systems. These alternatives and their estimated benefits and costs, as regards food justice, are summarized in the table 1.

<table x.1 near here>

| *Method* | *Benefits to food justice* | *Harms/risks to food justice* | *Efficiency in reducing climate harms* |
|---|---|---|---|
| SRM in agriculture | +Safe, cheap, reversible<br>+Local cooling effect decreases heat wave related harms<br>+May increase productivity | -Property rights or GM related threats to justice<br>-Risk of 'bio-perversity'<br>-Relatively unknown risks | Unknown |
| CDR in agriculture | +Safe, cheap, reversible<br>+Promotes food security by increasing production | -Price of sequestered carbon requires considerations | Modest |
| SRM, non-agricultural | +Very effective and quick<br>+Mitigation in food systems would become unnecessary<br>+Cheap | -May risk food security widely<br>-Unequally distributed harms<br>-Substantial anticipated and unanticipated risks<br>-Termination has high risks | Very high |
| CDR, non-agricultural | +Rather safe<br>+Few risks to food security | -Possibly high costs<br>-Termination has high risks | Modest |
| Mitigation in food systems | +Safe and rather effective<br>+Most policy options are compatible with food justice<br>+Other environmental problems in food systems are addressed | -Poorly designed policies might impede food justice<br>-Costs may be high (at least in the short run) | Relatively high |

We concur with the argument that while some climate engineering strategies can be considered as complements to mitigation policies, $CO_2$ mitigation is still the most effective way to tackle climate change (cf. Keller et al. 2014, 9). This concerns the great potential of mitigation in food systems as well. One reason that makes mitigation in food systems a superior alternative to (particularly non-agricultural) climate engineering is that due to other environmental impacts of food systems, climate engineering cannot replace the need to address the environmental effects of food systems whereas food system mitigation could partly address these as well, providing a valuable co-benefit.

More research on climate geoengineering is however needed. It is possible that in future some geoengineering techniques will prove to be useful for promoting food justice, if they safely decrease yield losses particularly in the poor or vulnerable communities as Keith (2013, 9–11; 58–60) has suggested with regard to (non-agricultural) SRM. It is necessary to find the ways to resolve or manage the risks related to non-agricultural SRM techniques (cf. Pongratz et al. 2012; Robock et al. 2010). It is also important to keep in mind that full-scale and moderate implementation of such techniques are different in their effects and related risks.

Considering how significantly climate change threatens food justice and food security, there are reasons for being cautiously positive towards those climate engineering strategies that are safe in terms of food justice and food security. Within our current knowledge, soil carbon sequestration, small-scale CDR techniques (with the exception of BECCS) and perhaps albedo geoengineering, with some reservations, already fulfil this condition. Soil-based CDR can be considered as the most justifiable option in these respects, because it will improve food production and food security regardless and the effects in terms of carbon sequestration will be either positive or neutral.

## References

Alkon, Alison H., and Julian Agyeman, eds. 2011. *Cultivating Food Justice: Race, Class, and Sustainability.* Cambridge: The MIT Press.

Boucher, Olivier, Piers M. Forster, Nicolas Gruber, Minh Ha-Duong, Mark G. Lawrence, Timothy M. Lenton, Achim Maas, and Naomi E. Vaughan. 2014. “Rethinking Climate

Engineering Categorization in the Context of Climate Change Mitigation and Adaptation." *WIREs Climate Change* 5(1):23–35. doi:10.1002/wcc.261.

Chen, Yu-Han, and Ronald G. Prinn. 2006. "Estimation of Atmospheric Methane Emissions Between 1996 and 2001 Using a Three-Dimensional Global Chemical Transport Model." *Journal of Geophysico-chemical Research* 111:D10307. doi:10.1029/2005JD006058.

Conte, Pellegrino. 2014. "Biochar, Soil Fertility, and Environment." *Biology and Fertility of Soils* 50(8):1175.

Ericksen, Polly J. 2008. "Conceptualizing Food Systems for Global Environmental Change Research." *Global Environmental Change* 18:234–45. doi:10.1016/j.gloenvcha.2007.09.002.

Foster, Chris, Ken Green, Mercedes Bleda, Paul Dewick, Barry Evans, Andrew Flynn, and Jo Mylan. 2006. *Environmental Impacts of Food Production and Consumption: A Report to the Department for Environment, Food and Rural Affairs*. Manchester Business School. Defra, London. http://randd.defra.gov.uk/Document.aspx?Document=EV02007_4601_FRP.pdf.

Garnett, Tara. 2011." Where Are the Best Opportunities for Reducing Greenhouse Gas Emissions in the Food System (Including the Food Chain)?" *Food Policy* 36:523–32. doi:10.1016/j.foodpol.2010.10.010.

Gottlieb, Robert, and Anupama Joshi. 2013. *Food Justice.* Cambridge: The MIT Press.

Holt-Giménez, Eric. 2011. **"**Food Security, Food Justice, or Food Sovereignty?" In *Cultivating Food Justice: Race, Class, and Sustainability,* edited by Alison H. Alkon, and Julian Agyeman, 309–30. Massachusetts: MIT Press.

IPCC. 2014a. Climate Change 2014: Synthesis Report. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. Geneva: IPCC.

IPCC. 2014b. Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P.

Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Keith, David. 2013. *A Case for Climate Engineering.* Cambridge: The MIT Press.

Keller, David P., Ellias Y. Feng, and Andreas Oschlies. 2014. “Potential Climate Engineering Effectiveness and Side Effects During a High CO2-Emission Scenario.” *Nature Communications* 5:3304. doi:10.1038/ncomms4304.

Lal, R. 2013. “Abating Climate Change and Feeding the World Through Soil Carbon Sequestration.” In *Soil as World Heritage*, edited by David Dent, 443–57. London: Springer.

Ling, Qihua, and Paul Jarvis. 2015. “Regulation of Chloroplast Protein Import by the Ubiquitin E3 Ligase SP1 Is Important for Stress Tolerance in Plants.” *Current Biology* 25(19):2527–34. doi:10.1016/j.cub.2015.08.015.

Lindenmayer, David B., Kristin B. Hulvey, Rirchard J. Hobbs, Mark Colyvan, et al. 2012. “Avoiding Bio-Perversity from Carbon Sequestration Solutions.” *Conservation Letters* 5:28–36. doi:10.1111/j.1755-263X.2011.00213.x.

Pongratz, J., D.B. Lobell, L. Cao, and K. Caldeira. 2012. “Crop Yields in a Geoengineered Climate.” *Nature Climate Change* 2:101–5. doi:10.1038/nclimate1373

Potrykus, Ingo. 2001. “Golden Rice and Beyond”. *Plant Physiology* 125(March):1157–61.

Powlson, David S., A.P. Whitmore, and K.W.T. Goulding. 2011. “Soil Carbon Sequestration to Mitigate Climate Change: A Critical Re-Examination to Identify the True and the False.” *European Journal of Soil Science* 62(1):42–55. doi:10.1111/j.1365-2389.2010.01342.x.

Preston, Christopher J., ed. 2012. *Engineering the Climate: The Ethics of Solar Radiation Management.* Maryland: Rowman & Littlefield.

Ridgwell, Andy, Joy S. Singarayer, Alistair M. Hetherington, and Paul J. Valdes. 2009. “Tackling Regional Climate Change by Leaf Albedo Bio-geoengineering.” *Current Biology* 19(2):146–50. doi:10.1016/j.cub.2008.12.025.

Robock, Alan, Bunzl, Martin, Kravitz, Ben, and Stenchikov, Georgiy L. 2010. “A Test for Geoengineering?” [Perspectives text] *Science* 327:530–31.

doi:10.1126/science.1186237.

Singarayer, J. S., and T. Davies-Barnard. 2012. “Regional *Climate Change Mitigation with Crops: Context and Assessment.” Philosophical Transactions of the Royal Society A: Mathematical, Physico-chemical and Engineering Sciences* 370:4301–16. doi:10.1098/rsta.2012.0010.

Steinfeld, Henning, Gerber, Pierre, Wassenaar, Tom, Castel, Vincent, Rosales, Mauricio, and De Haan, Cees. 2006. *Livestock's Long Shadow*. Rome: FAO.

Swann, A.L., Fung, I., and Chiang, J.C. 2011. Ecoclimate Teleconnections: Remote Control of the Mid-Holocene Green Sahara. *AGU Fall Meeting Abstracts* 1:0490.

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[i] There are food-related human engineering issues such as modifying the human size through the diet or funnies like engineering human digestive systems to make them less gaseous; these are aside the main theme.

[ii] The place of animals in food systems is thought-provoking; some species are important as sources of food but pure companion animals are merely consumers. This issue is not discussed here.

[iii] This is not true of all vegetation: temperate forests (in for instance the US, Canada, and Russia) absorb heat significantly, which is a concern about large scale afforestation (see Swann, Fung and Chiang 2011).

[iv] http://goldenrice.org/Content1-Who/who4_IP.php – accessed 12 October 2015.

[v] Similar problems have disturbed the use of patented drugs in the global South.