How agriculture and forestry change climate, and how we deal with it

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Contents

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The aim of LUC4C is to bring forward our knowledge about the interactions of climate change and land-use change. The scientists in LUC4C work on the development of complex earth system models, tools for providing an integrative assessment of the land-use change - climate change interplay, and guidelines for policy and other societal stakeholders. LUC4C seeks to identify and understand the societal and environmental drivers of land-use and land cover change (LUC), as well as why they are relevant to climate change. The project evaluates different mitigation and adaptation policies in view of how they affect important ecosystem processes, and whether (unintended) conflict with other ecosystem services related to LUC arise from the implementation of such policies.

In this booklet we have gathered articles about the interaction of land-use change and climate change, climate policy, the state of the art of climate models and scenarios, the connection to food production and the interaction with human societies.

I

Land-use change: what is it, and why does it affect climate change?

Almut Arneth

People have been transforming natural ecosystems to grow food, and to obtain firewood and timber, for millennia. Today, about 40% of the ice-free land surface is covered by crops or pastures, and in many parts of the world we continue to expand these areas because the world's population is growing, and this growth requires resources we obtain from the land.

When investigating the effects of transforming natural ecosystems, scientists often distinguish land-cover change from land-use change. Land-cover change describes the transformation of an ecosystem type, for instance the replacement of a natural forest or natural grassland with agricultural crops. Land-use and land-use change describes the way that crops, pastures, or forests are managed. This can include a change in the amount of fertiliser or irrigation applied, or animal grazing density, or a change in the tree species composition of a managed forest.

Land-cover change and land-use change both interact with climate change, and in this booklet we will not differentiate between the two; it is, however, important to be aware that both are aspects of what is termed here solely "land-use change".

Land-use change has many effects on climate change. The best known of these are identifiable via the greenhouse gas content of the atmosphere. Greenhouse gases like carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) affect the earth's climate and these gases have increased in the atmosphere due to human activities, especially over the last 100-200 years. The greenhouse gas concentration in the atmosphere can be measured directly from a set of observation stations around the world, but also, for instance, in air-bubbles trapped in glaciers – and these air bubbles can give us a very good record of greenhouse gas levels hundreds and thousands of years ago. The exact chemical signature of the greenhouse gas molecules (the so-called isotopic composition) helps to identify human activities as the main source for this increase.

When forests are replaced by pasture or crops, a large amount of CO_2 enters the atmosphere, most of it directly (if the forest is burned), or over the ensuing years (when the wood products are out of use and are subsequently burned or beginning to decompose). A lot of carbon is stored in the tree stems, but in addition the remaining tree roots die and are decomposed to CO_2 by soil organisms. Since crops and grasses do not have stems, and have less root biomass than trees, agriculture and pasture ecosystems contain less carbon in total than a forest – carbon is thus "lost" to the atmosphere upon deforestation. Carbon can also be "retaken" from the atmosphere if forests replace crops, but the area, globally, where forest increases is relatively small. It has been estimated that around one third of the total anthropogenic CO_2 in the atmosphere today originates from land clearance over the last decades to centuries.

Like CO_2, N_2O and CH_4 are important greenhouse gases. Around 50% of the N_2O that can currently be measured in the atmosphere may originate from agriculture, mostly from fertiliser use. Nitrogen-containing fertiliser is partially taken up by plants, to support growth. Part of it, however, remains in the soil, where microbes transform it into various N-containing gases, including N_2O, which then diffuses back into the atmosphere. CH_4 is also a by-product of soil microbial activities in rice paddies, produced by so-called methanogens. These microbes use dead plant material to "feed" themselves and to grow in conditions of low oxygen (found in rice because it is often grown in flooded soils), and CH_4 is the end-product of their metabolism. And, CH_4 is produced in the stomachs of ruminants, particularly cows. At present, rice paddies and livestock jointly contribute nearly half of the total annual man-made methane emissions.

These greenhouse gas emissions contribute to climate warming. Their effect is important for climate globally, because these gases are chemically low-reactive and long-lived, and therefore have plenty of time to become mixed in the atmosphere. They remain in the atmosphere for decades to many centuries, until they are eventually removed by physical or chemical processes.

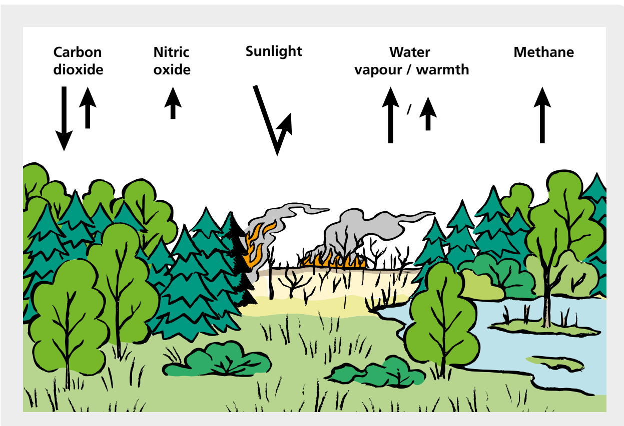
Land-use change also affects climate by processes unrelated to the emission of greenhouse gases. These processes are often summarised as "biophysical", and they operate by affecting radiation and evapotranspiration. In short, when sunlight hits the land surface, a proportion of this light is directly reflected back to the atmosphere, and the remainder is absorbed. The amount of reflection is called albedo, and the albedo of a dark surface is lower than that of a light surface. A forest landscape, therefore, has a lower albedo than a cropland or grassland, and this affects the forest's surface temperatures, as the absorbed sunlight is turned into heat. In ecosystems that are managed for food production, more sunlight is reflected compared to a forest, and thus their land surface temperature is relatively lower than that above a forest.

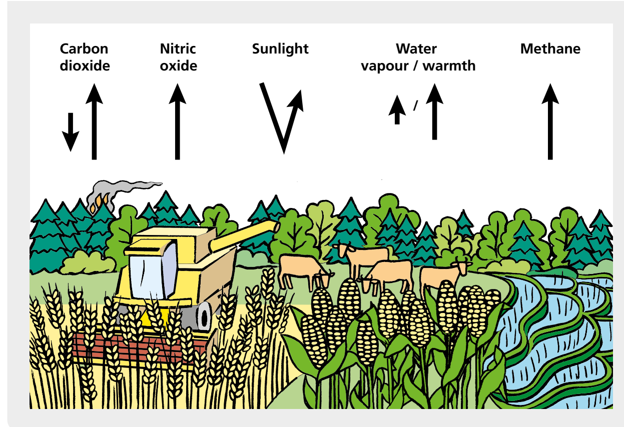
This is not where the story ends, however, because the absorbed radiation is only partially turned into heat; another part is used to move water vapour from ecosystems into the atmosphere. This process is known as evapotranspiration, and consists of water vapour loss from soils (evaporation) and from plants via their green leaves (transpiration). High evapotranspiration leads to cooling.

Whether or not a natural forest ecosystem will have higher rates of evapotranspiration than a crop or a pasture system is difficult to say: it depends, for example, on the global region in which the plants grow, the rooting depth of the natural versus the managed vegetation, and whether or not the crop is irrigated. In some regions, the occurrence of droughts has been linked to biophysical land-use change processes, but in other regions, land-use change can even yield a local cooling.

It is important to mention here a third effect of land-use change, beyond the aforementioned long-lived greenhouse gases and biophysical processes.

Land-use change is also an important consideration in relation to emissions of trace gases that act as a precursor to the formation of ozone in the lower parts of the atmosphere. In the lower air layers, ozone is a greenhouse gas which contributes to climate warming. Finally, aerosols and their precursors are also climate-change agents, with either a warming or cooling role. In contrast with greenhouse gas emissions, the effects of biophysical processes and of reactive trace gases and aerosols are therefore mostly restricted to the region where the change occurs, and can either contribute to a warming or cooling effect.





Climate-relevant exchanges between the land surface and the atmosphere.
Opposite page: In a pristine landscape, there is on average no (or little) net uptake or loss of the greenhouse gas CO_2, Photosynthetic carbon uptake and losses of carbon through (for instance) respiration and fire are in balance. Small sources of the greenhouse gases methane and nitrous oxide exist, in particular in wetlands and savannahs. A comparatively larger proportion of sunlight, compared to croplands, is absorbed at the land surface. More of the energy available via this absorption is used for transpiring water vapour.
This page: In a landscape used by humans, CO_2 is emitted by land-use change, while emissions of methane (through rice paddies and life-stock) and nitrous oxide (through use of fertiliser) greatly exceed emissions of these greenhouse gases in natural ecosystems. A comparatively smaller proportion of sunlight, compared to natural ecosystems, is absorbed by the land surface. Often, more of the energy available via this absorption is used to heat the land surface.

These many climate-related aspects of land-use change, and the fact that they operate over different scales of time (days to centuries) and space (regional to global), pose a large challenge when aiming to understand all the effects of past, present and future land-use change on climate. Furthermore, emissions and biophysics are not only determined by the way we use our land, but actually respond to climate change themselves; warmer temperatures will enhance the underlying biological and chemical processes, leading to enhanced emissions and biophysical processes. In this way, they feed back to climate change.

But does climate change also affect land use and land-use change? Clearly so; climate in a given region is an important determinant of the type of food or timber grown there, as it determines the available water for irrigation, and impacts yields (through, for example, droughts, floods, and frost). Climate change will thus affect harvests, both locally and regionally, either positively or negatively, which is one factor that influences how people choose to manage land. Climate is, nonetheless, only one aspect of such decisions, and other factors, such as economic, social or political change, are fundamental to the understanding of land-use change.

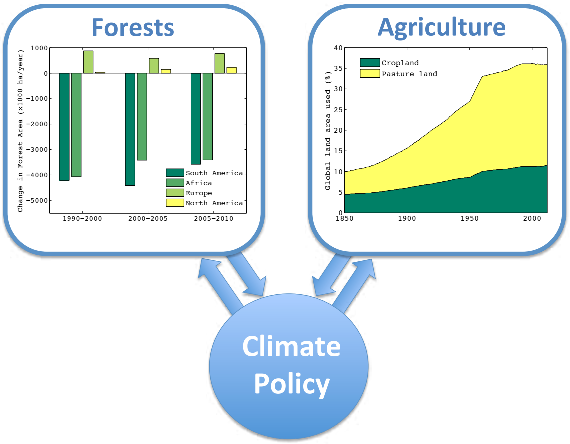
2 Land-use change in international climate policy

Joanna House & Annalisa Savaresi

Policies and decisions on how land is managed affect greenhouse gas emissions. International policy to measure and manage greenhouse gas emissions from the land sector has gradually been put in place. Virtually all states in the world have ratified the 1992 United Nations Framework Convention on Climate Change (UNFCCC), which requires them to:

- adopt national policies to limit anthropogenic emissions of greenhouse gases, and protect, maintain and enhance greenhouse gases storage in sinks and reservoirs
- periodically publish national inventories of greenhouse gas emissions and sinks using agreed methodologies

The so-called land use, land-use change and forestry (LULUCF) sector includes emissions and storage associated with conversions between land categories (e.g. from forest land, to cropland, from wetland to settlements, etc.) and as a result of activities on managed land within a category. Developing definitions and methodologies for LULUCF activities in international climate law has been a long and complex process. Two particularly difficult issues have been how to deal with: (a) permanence (e.g. a newly established or existing forest may be vulnerable to future human activity or environmental change, disease, fire, etc.); and (b) leakage (e.g. protecting or establishing a forest in one place may lead indirectly to forest being cut for agriculture in other places). Further difficulties have arisen from the fact that in some countries, like Australia or New Zealand, the LULUCF sector is a large greenhouse gas source, as a result of intensive cattle grazing and associated emissions of methane (see chapter 1). By contrast, in other countries the LULUCF sector is a greenhouse gas sink, for instance when crop areas are converted back into forest (like in many EU member states), or countries that may have large potential to avoid future deforestation (like in Brazil).



Land-use change contributes to climate change, and hence affects climate policy. But land use can also offer opportunities to mitigate climate change through appropriate policies.
Top left: Change in forested area (in 1000s hectares per year) for selected regions (source: Forest Resources Assessment, 2010). Tropical regions are still undergoing strong deforestation, whilst in some areas of Europe and North America the forest area expands, following e.g., abandonment of agricultural land.
Top right: Fraction of global land area used for either cropland or pastures (Klein Goldewijk et al. 2011, Glob. Ecol. Biogeogr. 20, 73–86). Conversion of natural land into cropland has increased historically very strongly, but with a declining trend over the last few decades.

Most parties to the UNFCCC have also ratified the 1997 Kyoto Protocol, which set legally binding emissions reductions targets for some developed countries for the period between 2008 and 2012. After lengthy negotiations, a somewhat smaller group of developed countries undertook a new set of emission reduction targets for the period between 2013 and 2020. Under the Kyoto Protocol, developed countries may use LULUCF activities to meet their targets. Accounting for emissions and removals from afforestation, reforestation, deforestation and forest management is mandatory, whereas countries can choose whether or not to account for other land-based emissions, such as cropland, grazing land and wetland management.

Developing countries can also participate in emission reduction activities in the land sector. Under the Clean Development Mechanism, some LULUCF activities (limited to afforestation and reforestation) can be performed in developing countries with finance provided by developed countries, which can then claim the resulting greenhouse gas reduction credits. More recently, developing countries were also given the possibility to access finance to carry out afforestation, reforestation, prevention of deforestation and forest management under REDD+ (Reducing Emissions from Deforestation and forest Degradation including conservation, sustainable management of forests and enhancement of forest carbon stocks).

Many developing countries have furthermore made pledges for voluntary emission reductions in the LULUCF sector, such as:

- Brazil proposes to reduce emissions by around one-third compared to the "Business as Usual emissions" in 2020, including reducing deforestation in the Amazon region by 80% between 2020, compared to the year 2005.

- China pledged to increase forest coverage by 40 million hectares and forest stock volume by 1.3 billion cubic metres by 2020, compared to the situation in 2005.

- Indonesia seeks to cut emissions by 26% to 41% by 2020 compared to "Business as usual emissions". Presently, about 80% of Indonesia's total emissions come from deforestation and peat fires.

- Mexico wants to reduce emissions by 30% below "Business as usual" by 2020, including programmes of REDD+ and afforestation.

Parties to the UNFCCC are in the process of negotiating a new climate agreement, which is expected to be adopted at the Paris Climate Change Conference in December 2015. The new agreement may include a dedicated REDD+ mechanism and new rules on land-use change, and possibly even legally binding obligations for some developing countries to reduce their emissions from LULUCF activities.

3 Models and methods for analysing LUC-climate change interplay

Nathalie de Noblet-Ducoudré

Measuring the impacts land-use change has on the atmosphere (and climate), with regard to greenhouse gas content, other land-use change-related substances, and heat and water, is challenging. One option would be to perform measurements at two experimental sites that have initially the same weather, with one of these sites then exposed to a land-use change. In this way, one can compare the situation in the "pristine" and the "disturbed" location. In practice it is, however, very difficult to find suitable locations that would allow for such types of controlled experiments. Moreover, a local distortion may not be sufficient, as the changes caused in the atmospheric state and/or composition at the disturbed site can also lead to changes in atmospheric motion (and hence the weather), which would also then influence the pristine location. The difficulty (or even the impossibility) of measuring the climate impacts of land-use change in situ has led to the development of models. These models are mathematically representative of our knowledge of how

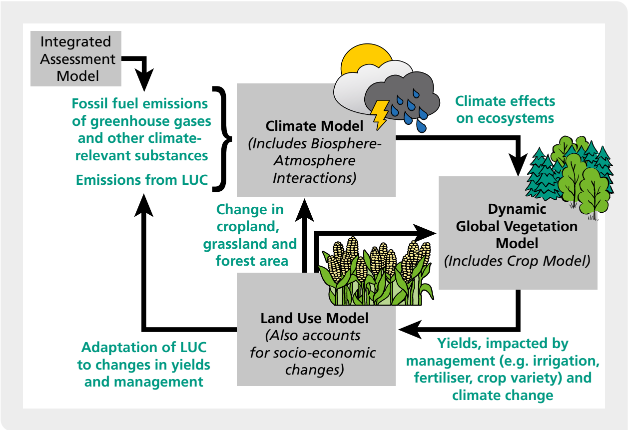
the given subject functions, enabling us to compare the differences between two contrasting situations, and helping us to explore how land-use change and climate change will interact in the future (or how they have done so in the past).

To account for the full interplay, we need three models. These models are interconnected in that information produced by one model is then used by another:

- **The global climate model** calculates the exchanges of heat, energy, water, greenhouse gases and other chemical compounds between the terrestrial & oceanic biospheres and the atmosphere, the flow of water from continents to oceans, the atmospheric winds & oceanic currents, and the chemical/physical/thermal state of the atmosphere. In order to assess how climate changes over time, for instance in response to human activities such as fossil fuel combustion, the climate model is fed with: a) atmospheric concentrations of greenhouse gases and aerosols, from both natural and anthropogenic sources, and b) the geographical distribution of land ecosystems and information regarding their uses (whether they are irrigated or not, harvested or not, etc). Changes in land use are provided as inputs to the climate model which then produces as outputs the land-use change-induced alterations in climate (diurnal and seasonal fluctuations of temperature, rainfall, wind, etc.).

- **The dynamic global vegetation model** (DGVM) mimics the functioning of the terrestrial biosphere. It embeds a representation of natural and managed ecosystems, and calculates the biosphere's life cycle: plant photosynthesis, respiration, plant growth and competition for water, sunlight and nitrogen. In geographic locations with managed ecosystems, irrigation and fertilizer can be applied, and annual crop yields calculated. The DGVM needs a set of atmospheric variables that comes from the climate model (for instance radiation, air temperature and humidity, CO_2 concentrations, rainfall, wind) that are needed to drive the biosphere's functioning. As for the climate model, alterations in land-use change are provided as inputs to this DGVM.

- **The land-use model** (LUM) is applied to study how humans have used the planet for agriculture and for pasture. Land-use change models take into consideration changes in human population density, as well as income levels, estimates of how technology develops and also people's lifestyles (for instance, a preference for certain food types). A representation of general economic principles is combined with social and natural system constraints (like the amount of yield that can be achieved in a certain region, due to the local climate and soils, e.g., from the DGVMs). These models also require information about the foreseen development of human societies (see chapter 4), and simulate changes in land use that are needed by the climate and vegetation models. Presently, Integrated Assessment models are typically used to provide the required land-use change projections in the drawn modelling framework (chapter 4), but there are also alternative LUM approaches under development that seek to consider in more detail the human decisions that lead to land-use change.



The Figure shows information flow between the various sub-models that are used to assess the land-use change - climate change interplay. Green text summarises the information produced by the individual models, black arrows show the direction of how this information is passed between the models.

Alterations in land-use change simulated by the LUM affect climate, for example through changes in greenhouse gas emissions, or surface characteristics such as albedo (see chapter 1). Those changes are taken into account by the climate model, and impact fluxes such as water, energy, and heat, at the biosphere-atmosphere interface, and thereby climate.

4

What are socio-economic emission scenarios and what are they good for?

Detlef van Vuuren & Elke Stehfest & Alexander Popp

Given the inertia in the climate system, it is important to assess the potential long-term consequences of decisions made today. Scenario analysis has been developed as a tool to explore and evaluate the extensive uncertainties associated with possible future developments. For instance, these scenarios can combine assumption on the growth of the earth's human population, economic and technological development and trade patterns. In recent years, the need for scenarios that integrate across the different climate change research communities has become clear. These scenarios allow us to bridge research into understanding the climate system, into climate-change impacts, adaptation and vulnerability, and into future anthropogenic greenhouse gas emissions and options for mitigation. The emissions from these scenarios are, for instance, used in the model-framework explained in chapter 3. Currently, these scenarios are organized around two important dimensions: the representative concentration pathways (or RCPs) describe a range of possible emissions pathways leading each to a specific level of radiative forcing, which determines the amount of climate change, and the associated climate-change impacts. The possible future socio-economic conditions that correspond to individual RCPs are then described in the shared socio-economic pathways (SSPs).

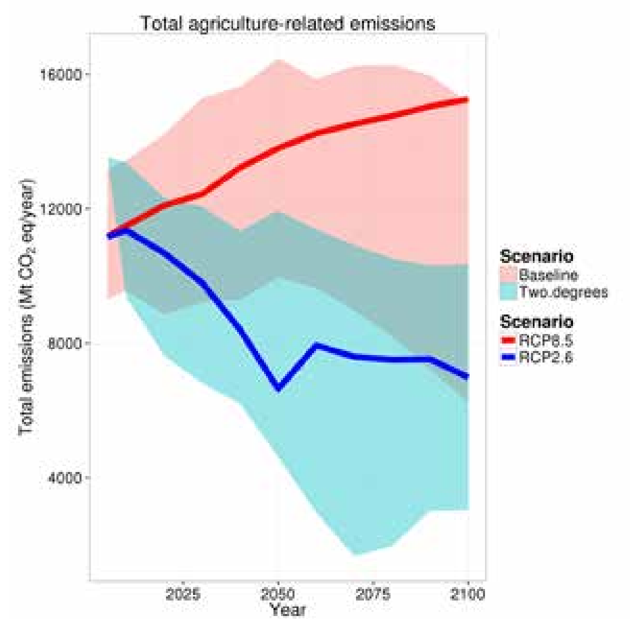
Land use plays a key role in these scenarios. The SSPs provide five alternative stories of future socio-economic development, including possible trends in agriculture and land use. Such SSPs could, for instance, describe a future world of investment in environmental technology, low population growth, high standards of education, and reduced economic inequality. Another SSP might follow a future path that is not very different from history, including continued population growth and fossil fuel burning. In each of the SSPs, climate policies can be introduced to reduce emissions to reach concentration levels consistent with the RCP scenarios. Land use related policy measures play an important role in this, including, for instance, the use of bioenergy, measures related to forestry, and reducing non-CO_2 greenhouse gas emissions from agriculture.

What models are used to develop the RCPs and SSPs?

Future emissions are a function of complex interaction between all kinds of socio-economic factors, including population dynamics, economic development, technological change, cultural and institutional changes, and policies. So-called integrated assessment models (IAMs, see chapter 3) have been developed as a consistent framework to study possible future pathways for these drivers, concentrating on energy and agriculture/land-use systems and associated emissions.

Land use futures are uncertain

Different studies in the past have looked into potential land-use futures. Most of these projections indicate that in the next few decades the area and agriculture continues to grow slowly, driven by an increase in demand for food and fodder outpacing the simultaneous expected increase in agricultural yields.



The graph shows worldwide LUC emissions (in equivalents of CO_2) of the scenarios in the AR5 IPCC database for a baseline ("business as usual") scenario compared with a scenario that aims at climate change not exceeding 2 °C (shaded red and green areas are due to a range of IAM output that represents the scenarios). The corresponding RCPs (RCP8.5 and RCP2.6) are drawn as lines. Reducing the land-use related emissions can contribute to climate policy, such as achieving the 2-degree target, but it is also clear that it is not possible to bring these emissions to zero. (Data based on IPCC AR5-WG3 Scenario database and RCP scenarios)

The degree of land-use expansion depends on uncertain trends in population growth, dietary changes, possible demand for non-food products such as bioenergy and future developments in agricultural yields (in turn being determined by technology and environmental impacts, such as climate change). Over time, these uncertainties may result in very different land-use change patterns. Many scenarios, in fact, show a stabilization of land use in the absence of climate policy. With climate policy (see chapter 2), however, future demand for bioenergy may lead to a further "claim" on fertile agricultural land. This could result in a further loss of natural areas, but also in higher agricultural yields in response to land scarcity.

The climate impacts are obviously also uncertain. While in the past few years model-based studies have started to explore the biochemical impacts of land-use change under different scenarios, the exact changes in the earth's carbon cycle are still unknown. Moreover, the biogeophysical impacts of future land-use change, such as those related to absorption and reflection of light (see chapter 1 and 3), have not often be studied and can be strong at a local scale. Coupling IAM models, biophysical models, such as DGVMs, and climate models, as done in LUC4C, allows us to explore the relevant relationships between land use and climate change in a unique way.

5

The interconnected web of food production, climate and society

Thomas Pugh

All organisms modify the environment around them to better suit their needs, but ever since the birth of agriculture around 10 000 years ago, humans have been doing so quite profoundly. Agricultural systems can differ markedly from the ecosystems they replace, in the most extreme cases replacing biodiverse forests with large expanses of monoculture crops. As stated already earlier in this booklet, 12% of the global land surface is occupied by cropland, with a further 25% used for grazing. Overall, approximately 25% of the sun's energy captured by plants is now appropriated for human use.

The area of cropland required to support human societies depends on the human population reliant on it, their dietary preferences, and the productivity of the cropland. Cropland coverage has increased greatly with the dramatic rise in global population over the last 500 years but, more recently, much of the required increase in food production has been met by modern farming practices, such as fertilisation, mechanisation, breeding of more productive crop types, and suppression of natural pests. Many projections of how the global population will be fed in the 21st century (see chapter 4) are based on the idea that technological advances will continue at the rate of the last half century, or that places where these advances have not yet been effectively implemented, often developing countries, can realise large increases in agricultural production through transfer of these technologies. It is far from clear, however, if these projections and their underlying assumptions are realistic.

Temperature increases or changes in rainfall as a result of climate change can have a profound effect on crop growth. In addition to the obvious effects of drought, heat-waves during the flowering stage can substantially reduce the yields of grain crops. Furthermore, extreme weather events such as floods or hailstorms, which are expected to increase in intensity under climate change, can destroy crops in the field. The combination of these factors can act both to reduce crop yields, and to make them less reliable. As is so often the case, these negative effects are not expected to be spread equally across the globe, but are instead concentrated in tropical regions, where crop production is often already marginal.

It is not all bad news, however; croplands in much of the middle latitudes are actually expected to become more productive as a result of increasing temperatures lengthening the growing season. Furthermore, whilst carbon dioxide drives increases in temperature, there is abundant evidence to show that it also increases the rate at which plants photosynthesise. It is thus possible that increases in crop yield due to the direct effect of carbon dioxide on plants could counterbalance the decreases in yield due to the effect of carbon dioxide on climate.

Carbon dioxide also reduces the water requirements of crops, something that may be very important in arid regions, or those regions likely to become arid under a changing climate. The overall effect of carbon dioxide and climate change on crop yields is, however, very uncertain. Experiments show a mixed response, and no-one knows for sure how yields will respond. There are also questions over whether increased carbon dioxide will change the quality of crops; there is some evidence that it may decrease the protein and mineral content.

Clearly, climate-driven changes in crop production will have a strong bearing on the amount of cropland required, and where it would best be located. In the face of falling yields, agricultural expansion or re-location of croplands may be the only way to increase food production, yet there is little unused land on this planet. Moving or increasing cropland area will always come at the cost of some other function provided by ecosystems, for instance carbon storage (see chapter 1). Natural ecosystems store huge amounts of carbon, twice to three times the amount in the atmosphere. Although there are some exceptions, croplands tend to store less carbon in both vegetation and soils than the natural systems they replace. The harvesting of crops removes material that would otherwise end up stored in the soil. In addition, processes such as tillage open up the soil structure, increasing both the likelihood of soil erosion, and the rate at which carbon-containing substances in the soil are decomposed into carbon dioxide. The actual amount of carbon lost varies with climate, crop, soil type and farmer choices. For instance, farming methods which avoid tilling, and which leave the non-food part of the crop on the field, can greatly reduce such losses.

These effects of agriculture on greenhouse gases can even lead to feedback effects; reductions in crop yields due to climate change, for instance, may lead to cropland expansion, reducing carbon storage and increasing emissions of other greenhouse gases, and thereby increasing climate change, which in turn further decreases crop yields. The opposite is also possible. Therefore, in order to understand human land-use requirements in the future, it is critical to understand how crop production will evolve under climate change and associated socio-economic changes. But simultaneously, to understand climate change, we must also know how croplands will expand or contract, or how their management will change.

There are also questions of whether socio-economic systems are able to transport food from where it is best produced to where it is most required, or whether economic realities may dictate a course of agricultural land use that does not follow the theoretically-optimal path. The fundamental interconnection of these many human and natural systems poses a huge challenge to researchers. Unravelling this complex picture is key to understanding how to adapt to the unavoidable effects of climate change, and how to effectively mitigate against the most extreme changes. Without such a holistic understanding, efforts to maintain our food supplies or to limit climate change to a reasonable level will rely more on luck than judgement.

6

Bioenergy, land-use change and climate

Almut Arneth & Kerstin Baumans

The term 'bioenergy' refers to the numerous forms of biomass used for generating energy in the form of fuel, electricity or heat. Biofuels like ethanol, biodiesel and biogas are produced through conversion of plant materials that are rich in starch (e.g. maize) or oils (e.g. oil palm, oilseed rape). Woody vegetation is naturally the most traditional form of bioenergy and, until about a century ago, biomass used for heating and cooking was the biggest energy source globally. With the accelerated use of fossil fuels, especially in the industrialised world, the contribution of bioenergy had declined drastically since then, but over recent years, climate change mitigation policies (see chapter 2 and 4) have promoted the use of bioenergy. As a consequence, in countries and regions like China, the EU, the US and Brazil, bioenergy production has increased up to threefold since the beginning of the 21st century.

How much of the total global energy demand could be supplied from plants is difficult to assess. Optimistically, up to 400 Exajoules (EJ) per year could be reached by 2050. This number is fairly meaningless to most people, but such an energy supply through biological sources would be equivalent to two thirds, or even more, of the present annual global primary energy production. But other assessments use a much lower value (around 100 EJ per year). Underlying this wide range are uncertainties as to how much energy could be derived from biomass sources, which depend on assumptions about the future development of plant productivity, the efficiency of converting plant materials into different forms of fuels, and uncertainties regarding the area of land available for biomass production.

The promotion of bioenergy for climate change mitigation is based on the notion of a closed cycle; only carbon that has been taken up during the plant's growth is released during the conversion and combustion. However, studying the climate effect of bioenergy should include consideration of the energy required to convert plant materials into liquid or gaseous forms or aerosol particles that are a by-product of combustion. Most critically, N_2O emissions from nitrogen fertilizers appear to affect the greenhouse balance of bioenergy more than initially thought, especially in intensively produced biofuel crops such as sugar cane or maize.

Concerns have also been raised that bioenergy production, especially biofuels generated from starch and sugar crops, compete directly with food production and, in this way, contribute to high food prices and accelerate natural land conversion. A study that investigated the land-area needed for the growth biomass either converted into biofuels or used for electricity generation found that cars using electricity travel, on average, 80% further than cars fuelled by liquid biofuels for the same area of land. Enhanced use of bioenergy from purpose-grown biomass crops can thus lead to land-use change, including so-called indirect land-use change, when new areas for food production are established elsewhere to compensate for the reduced food production in a given region.

Both direct and indirect land-use change can lead to a loss of carbon stored in the original vegetation and soils, which counteracts the CO_2 emissions saved through the combustion of bioenergy instead of fossil energy. This effect depends critically on the type of ecosystem that is converted, and the efficiency of using plant biomass for energy production. The negative impacts can be drastically reduced by the use of by-products rather than purpose-grown bioenergy. When done carefully, bioenergy production and food production can co-exist successfully, and can be beneficial for rural development and rural incomes.

7

How will land-based sectors adapt to climate change?

Mark Rounsevell

Since the first establishment of the scientific evidence for climate change, there has been a political focus on reducing greenhouse gas emissions to mitigate the problem (see chapter 2). Increasingly, however, the realisation has come that the world is already committed to some level of climate change, which leads to the need to understand climate change impacts, and to plan for adaptation to these impacts. There are many ways in which individuals and societies can adapt to climate change, some of which can lead to opportunities and multiple benefits.

Different types of land managers have different ways in which they could adapt to a changing climate. For agriculture, this includes shifting to more heat-tolerant crop varieties, or changing crop sowing and harvesting dates to better correspond with changing weather patterns. Farmers can even modify the agricultural system itself (e.g. from grassland to crop cultivation) through land-use change. Diversifying the number and types of crops cultivated can also minimise the risks associated with a more variable climate, which in itself would have potential benefits for nature, in creating a wider range of habitats for natural species. Farmers can also adapt to warmer and drier conditions by introducing irrigation schemes, especially if these involve on-farm water harvesting and storage, which minimises the impact on the wider hydrological system through river and groundwater abstraction. Indeed, warmer conditions may even lead to greater opportunities for some land managers, for example by increasing the potential for viticulture and wine production as well as the production of other fruits at higher latitudes.

Likewise for forest managers, warmer conditions at higher latitudes offer the potential to introduce a wider range of tree species, provided the need to do so is anticipated sufficiently early, since trees have very long rotation times commensurate with the rate of future climate change. In natural areas, biodiversity can be helped in adapting to climate change by physically moving less mobile species from one location to another (known as species translocation). Nature managers can also enhance the connectivity of existing nature reserves through the development of ecological corridors (known as green infrastructure). Flooding is a major potential impact of climate change, but the re-establishment of natural wetlands can guard against future climate-mediated flood events (by acting as a buffer for excess water) as well as provide new conditions for wetland species such as migratory birds. This type of win-win situation can be implemented both in riverine systems and along the coast, where re-aligning coastlines through managed retreat involves removing sea walls and using saltmarsh vegetation as a natural barrier to coastal flooding and sea level rise.

All of these examples of adaptation rely on individuals, or the broader communities within which they live, anticipating the potential impacts of climate change and implementing appropriate response strategies. This requires prior knowledge of climate change impacts, but also a willingness to engage in long-term land management strategies of benefit to everyone.

8

Sustainable Land Use: Elinor Ostrom's Alternative

Mechtild Agreiter

"The road we have long been traveling is deceptively easy, a smooth superhighway on which we progress with great speed but at its end lies disaster. The other fork of the road -- 'the one less travelled by' -- offers our last, our only chance to reach a destination that assures the preservation of our earth."

Rachel Carson made this statement in 1962, in her book *Silent Spring*. Already, she could see that "we are being asked to take senseless and frightening risks". Carson believed that we should take responsibility and identify for ourselves the other paths available to us. What could this mean in the context of land use and climate change?

Land use today, alongside our rapidly changing climate, poses challenges for us that we often try to meet with technical innovations. In doing so, such challenges deceptively appear simply as a question of natural sciences, with little or nothing to do with human values and ethics and, consequently, social change. Elinor Ostrom has emphatically demonstrated that technical solutions are not enough without the crucial step of altering human social behaviour. Instead of looking to nationalization and privatization, she envisaged a third option: the possibility of a co-operative approach, even within complex systems. In 2009 she became the first woman to win the Nobel Prize in Economic Sciences, for her research in the field of sustainable use of common resources (or 'commons'). The value of her work lies in the evidence that the commons need not, and must not, be used in an economically and ecologically destructive manner. Through multiple studies, Ostrom has shown that the participants can find successful rules for collective and sustainable land use.

Ostrom outlines eight 'design principles' that could be viewed as instructions for the use of a commons such as land and/or climate.

Elinor Ostrom's design principles for the successful and sustainable management of a commons:

1. Clearly defined boundaries
2. Coherence with local needs and conditions
3. Collective decision-making
4. Monitoring of users and resources
5. Scale of graduated sanctions for rule violators
6. Conflict resolution processes
7. Recognition of rights
8. Polycentric structure of governance, with nested (accountable) institutions

Ostrom's assumption is that people will voluntarily abide by such rules in specific local contexts, and that they will look beyond their own maximum benefit, especially when this can resolve social conflict. Such a system could also work in the context of climate change and land use. The crucial point, as underlined by Ostrom, is that people take responsibility and organise themselves, working together to find solutions that take into account local needs and conditions, and involve all stakeholders.

One of the biggest challenges for such a system is to create the conditions for successful implementation; for a sustainable self-organisation of actors, or for a genuine voice for individuals, that increases the sense of (collective) responsibility and thus leads to a more sustainable use of the land resource.

When considering the deforestation of rainforests or the massive so-called 'land grabbing' of the last years, with its often devastating effects, it is clear that land use could be seriously, and positively, altered, as a result of applying Ostrom's principles.

The establishment of multiple small initiatives in many places of the world could make more sense than waiting for globally-organised remedies or international conventions. It is self-evident that this proposed system should be supported by policy. As the Nobel Committee stated, the future of the people belongs to “the organization of cooperation”. For such change to succeed, the focus must be shifted onto people, rather than technical advancements and the selective interests of the few. Rapid action is required, especially when considering the advancement of climate change, global social disparities, and world hunger.

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Figures
Almut Arneth (p. 16/17); Thomas Pugh (p. 22); Nathalie de Noblet & Almut Arneth (p. 30)

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