Towards a Great Land-Use Transformation?

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The Climate Change Challenge and Land-use Mitigation Options

Climate change poses great threats to many compartments of the Earth System and, as a consequence, to human societies. There is growing scientific evidence that a rise of the global mean temperature by more than 2 °C (as compared to pre-industrial levels) would irreversibly harm many ecosystems and most likely exceed the adaptive capacities of many societies. In order to confine global warming to maximally 2 °C, major efforts to reduce emissions of greenhouse gases are required. These may even include 'negative emissions' of carbon dioxide to be achieved by the second half of this century: carbon dioxide may have to be actively removed from the atmosphere and deposited on land for many decades, centuries, or even millennia.

The transformation of the energy system, steering away from fossil fuels, will have to contribute the lion's share of emission reductions. However, land-use changes are currently responsible for one third of total greenhouse gas emissions, so improved land management and productivity increases on land under cultivation could significantly contribute to climate change mitigation since soils and forests store large amounts of carbon.

Several techniques that would allow for negative emissions are currently discussed: afforestation and the restoration of peat and wetlands would be the most easily accessible options. Other options such as technologies for *carbon capture and storage* (CCS) in the energy sector involve sequestration of carbon dioxide in geological formations underground. Carbon dioxide could be directly extracted from the atmosphere making use of chemical reactions turning the greenhouse gas into solid carbonates. The large-scale application of these technologies is however still in its infancy. The most promising mechanism to achieve negative emissions is to fuel power plants with biomass, extract carbon dioxide from the exhaust and sequester it underground. However, in order to draw down a really significant amount of carbon dioxide, enormous quantities of biomass would have to be processed this way.

Increasing Demands on Land and the Need for Adaptation

In many regions, most of the available resources of fresh water and fertile land are already being used excessively, either directly for the production of food, fibre, and timber, or indirectly as carbon sinks, for water and air purification, nature conservation, and many other ecosystem services. This scarcity of basic resources is amplified by a non-sustainable use, causing degradation of ecosystems and production potentials. Fifteen per cent of the global land surface (about 2 billion hectares) are currently considered as being degraded – due to overgrazing, deforestation, over-exploitation and non-sustainable agricultural practices.

Since the year 2000, global agricultural supply has not kept pace with an increasing demand for food and bioenergy. The food price spike in 2007–2008 and related food riots in more than 60 countries had many underlying causes, but increasing demand in large emerging economies and dwindling stocks were certainly part of them. High oil prices and subsidies for biofuels in rich countries urged farmers around the world to allocate land and other factor inputs to energy crops, thus reducing the production of staple food crops. Continuous droughts, e.g. in Australia, added more pressure on food markets. Finally, an underlying cause of stagnating productivity increase in

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agriculture is a lack of funds for research and development.

In most countries, land prices insufficiently reflect the growing imbalance between demand and supply of fertile land. However, first conspicuous signs of land shortages have emerged. Large companies and even countries are already trying to stake their claims globally, a process known as 'land-grabbing'. In addition to buying food on the world market, several governments and large companies lease or buy land abroad, and ship the products back home. Advocates of these deals emphasize that poor countries may gain from access to new seeds and advanced farming practices. However, leasing land to financially powerful investors has also sparked conflict in the recent past. In Madagascar, public hostility to a deal that would have leased 1.3 million hectares to a South Korean company – half of the country's arable land – contributed to the overthrowing of the government. While foreign investors mostly secure land to improve food security in their home countries, an increasing number of projects involve growing biomass for fuel production. China has recently succeeded in leasing 2.8 million hectares in the Congo to construct the world's largest palm oil plantation.

Climate change is expected to increase these pressures and further reduce land productivity in many regions (chap. xy by Brauch/Oswald Spring). The need for climate change adaptation is evident – already today. Most developing countries are located in the lower latitudes, they are dependent on agriculture, they will be strongly affected by climate impacts, and they have lower adaptive capacity (chap xy by Adeel; chap xy by Galil Hussein; chap xy by Arredondo/Huber-Sannwald; chap xy by Bikienga). People migrate from degraded to more fertile areas, from the countryside to cities, from regions that cannot provide sufficient resources to sustain people's livelihoods to more fortunate places. The war in Sudan, for example, has partly been blamed on the competition for water supplies and grazing lands. About 155 million people worldwide are known to be currently displaced by environmental conflicts and natural disasters (chap. xy Guha-Sapir/Vos). This number could significantly grow under climate change as more people are expected to be affected by water shortages, sea level rise, deteriorating pasture land, and crop shortage.

Negative climate impacts on agriculture may be reduced through a range of adaptation measures. Adjustments in production technology and soil management, crop insurance schemes, modified agricultural policies, and diversified international trade flows can improve regional food availability and security of farm incomes. Creating more options for climate change adaptation and improving the adaptive capacity in the agricultural sector will be crucial for improving food security and rural development, and for preventing an increase in global inequality in living standards in the future (chap. xy by Safriel; chap. xy by García Lorca). However, at present, these improvements are often blocked by the lack of information, financial resources and good governance in the developing world.

The Earth's Carrying Capacity Conundrum

Mismatches between the demand and supply of land and its services already exist today. They could increase in the future not only due to climate change but also due to human population growth. Until the year 2100, human population is projected by the UN to grow up to 9–12 billion people, while already today about 1 billion people are undernourished. Changing lifestyles will further accelerate demand growth as people start to consume more goods that are produced with large amounts of energy, land, and water (such as meat) as soon as they can afford it.

The increasing competition for land and water resources between production sectors, ecosystem services, and regions raises the question of the Earth's carrying capacity for humans.[1] The first known attempt to answer the question of how many people the Earth can support was undertaken in the late 17th century. By extrapolating the population density of the Netherlands at that time to the global scale, Antonie van Leeuwenhoek in 1679 calculated a maximum human population of 13.4 billion people, which is astonishingly close to current UN projections of maximum world population.

Estimates of the human carrying capacities since then have varied substantially in a range of below 1 billion to more than 1 trillion people. Magnitudes reflect surprisingly well optimistic or pessimistic contemporary beliefs on the pace of technological progress and future development of energy supply. The broad range of possible lifestyles and accompanying usage

1 Ecologists define 'carrying capacity' as the population of a given species that can be supported indefinitely in a defined habitat without permanently damaging the ecosystem upon which it is dependent.

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patterns of energy, land, and water complicate a direct assessment of the human carrying capacity. Estimating the human carrying capacity in any serious manner therefore requires first of all answers to a set of crucial sub-questions:

- Solar energy is theoretically infinitely abundant and could be harvested to fulfil all global energy needs. However, is it feasible given the current state of technology?
- It has been shown during the past 'Green Revolution' that agricultural productivity can be increased by 2 per cent per year for some time, but can this be sustained for another half a century into the future?
- How much land will be available for food production, while other land-use types for forestry, energy, infrastructure and settlements, and nature conservation also have to be taken into account?
- Agriculture accounts for 70 per cent of global freshwater use. How can agricultural water use be reduced in the future, in order to meet increasing demands from households and industry?

Defining a realistic set of assumptions on limits to technological change, energy generation, and the availability of land and water is a most difficult task. Consequently, it is more promising to undertake the *inverse* exercise and, instead of aiming at an estimate of the human carrying capacity, to ask the question: How much land, water, agricultural productivity increase, and financial resources are required to feed 9–12 billion people in a sustainable manner, i.e. without exhausting the planetary regeneration capacities?

With the given competition for the scarce resources of fertile land and water, higher production on currently used areas is a necessity. Assessments show, however, that average productivity of current cropland needs to be increased by 70 per cent by 2050 if only population growth and changing diets with rising income are considered. If further climate change impacts and increasing demand for bioenergy are taken into account, agricultural productivity may need to be increased by 150 per cent by 2050. This would be equivalent to an average annual growth rate of 2.3 per cent in land productivity over the next 40 years.

The historic development of agricultural productivity puts this challenge into perspective: The overall increase over the period 1961-2005 was approximately 1.4 per cent per year. These growth rates could be achieved because of large-scale application of artificially synthesized nitrogen (Haber-Bosch process) and chemical pest control, but also improvements in cropping methods, mechanization, and breeding. These technological advances allowed for agricultural production to keep pace with past population growth and diet changes, including rising consumption of animal products, which require higher inputs of nitrogen, water, and land per calorie produced than vegetal products. It is, however, questionable whether technological innovation and further intensification of agriculture will bring about the productivity rise needed to feed 9–12 billion people on a planet suffering from climate change and land degradation.

Water scarcity may be technically overcome by improved desalination. However, this depends on the availability of clean energy as well as on future cost reductions for desalination technologies. Aquaculture has the potential to provide an increasing share of world food supplies, but it is not without its own sustainability challenges regarding feed and nutrient management. In other words: It seems unlikely that improved management and technological change alone will suffice to counterbalance the increasing pressure on land and water resources.

The Great Land-use Transformation

Climate change and the scarcity of land and water resources are global-scale challenges to humankind and therefore require global-scale transformations in the energy and food systems. However, initiating and managing major socio-economic transitions is often impeded by path dependencies – or so-called "QWERTY phenomena": Q-W-E-R-T-Y are the first six letters on the upper left part of an English typing keyboard. As a matter of fact, this arrangement of symbols has become an iconic constituent of our technical culture. Interestingly, the arrangement of letters on modern computer keyboards is by no means optimized with respect to the frequencies of use defined by the language. Instead, the key configuration probably originates from some mechanical requirements for the first typewriters built in the 19th century. Similarly, societal processes are often locked, through historic pathways, into certain patterns, which are defined by past knowledge and technologies and which can only be changed through major investments and/or behavioural changes. New and potentially radical ideas and actions are needed to overcome these lock-in phenomena.

Current land-use patterns have developed over hundreds of years, largely reflecting heterogeneous

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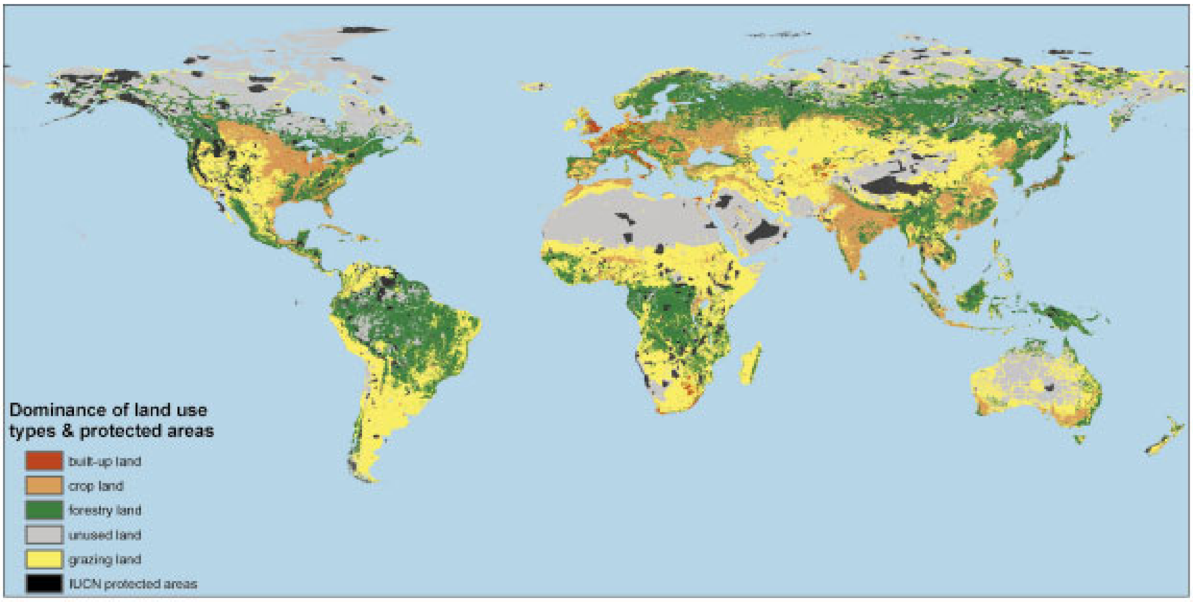
Figure 1: Global map showing current dominant land-use types: agriculture (including cropland, managed pasture land and rangeland), forestry, infrastructure and settlement, unused land, and nature conservation (protected areas as listed by the International Union for the Conservation of Nature, IUCN). Areas that are used for renewable energy generation are either included in the cropland category (in the case of bioenergy) or are not represented in the map (in the case of e.g. solar thermal power in the deserts and onshore/offshore wind energy production). **Source:** Data sets on global land-use types, i.e. built-up land, cropland, forestry land, unused land, and grazing land were provided by Erb, Gaube, Krausmann, Plutzar, Bondeau and Haberl (2007).[a]



a. Currently protected areas and restricted management areas were captured by overlaying data sets on IUCN protected areas category I to VI, i.e. nature reserves and wilderness areas, national parks, natural monuments, habitat/species management areas, protected landscapes, and protected areas sustainable use of natural resources (UNEP-WCMC 2007). Data sets were integrated at a spatial resolution of 5 arc minutes, i.e. 8.3 km times 8.3 km at the equator. By rule, the land-use type bearing the maximum fraction per grid cell was defined as dominant. Built-up land which covers 10 per cent of the grid cell at a minimum was intuitively added in order to emphasize the presence of rural and urban built-up areas, industrial and transport facilities, as well as other urban areas. The IUCN protected area cover entered as a separate layer independent of the underlying land-use types. The map was produced by means of ArcGIS v. 9.2 and R v. 2.8.1.

distribution and growth of population density and productivity of the land. From a local perspective, land-use patterns have been well adapted and optimized given local resource and market conditions and constraints. However, the globalization of trade has made some parts of these local multi-purpose land-use mosaics obsolete. About 10 per cent of the total raw production of food, fibre, and forest products is traded around the world, and a much higher percentage could be allocated reasonably by the global market. Still, land-use patterns determined by history are largely persistent. This lock-in situation can be partly explained by transportation costs and the inertia of land-use patterns due to large investments required for land conversion. However, another factor is societies' and countries' desire to remain largely autonomous with respect to their most fundamental resources: food and water.

If humankind wants to manage the climate change challenge through a cooperative global strategy, such heterogeneous land-use patterns for agriculture, forestry, energy, infrastructure, and nature conservation (figure 1) may have to be questioned. If productivity cannot be increased to similar levels across the globe, due to a variety of bio-physical, social, institutional, and economic reasons, a larger share of production may have to be concentrated in the most productive areas instead. Studies show that optimal spatial allocation and specialization can, in theory, strongly reduce the area needed for agricultural production, literally leaving room for other purposes such as bioenergy production, afforestation for carbon storage, or nature conservation (figure 2).

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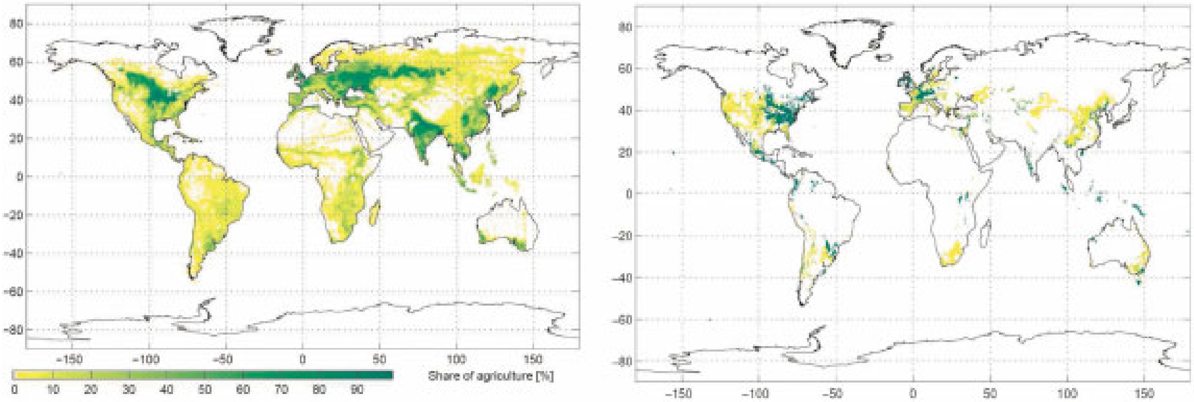
Figure 2: Observed global agricultural land-use pattern of 1995 (left panel) versus globally optimized pattern that would allow feeding 12 billion people with 1995 dietary habits (right panel). Agricultural areas shown in right panel correspond to roughly one third of the area currently used for crop growing. **Source:** Figures were taken without modifications from Müller, Bondeau, Lotze-Campen, Cramer and Lucht (2006).[a]



a. Details on data used, underlying assumptions and optimization algorithm can be found in the publication.

The world's regions have heterogeneous potentials and different land-use categories also have very heterogeneous demands. Climate change will certainly require reallocating some of the land-use types on the planetary map simply for ensuring their functionality. There is an ongoing debate about advantages and disadvantages of segregating versus integrating nature conservation and agricultural production at the local scale. But the climate change challenge requires lifting this discussion also to the global scale. In the future, specific migration corridors may be needed which allow species to move with changing climate patterns. Agricultural areas will be abandoned if they are degraded or fall dry. Settlements may also have to be moved if droughts, heat waves, hurricanes, and floods occur more frequently, or if sea level rise threatens to inundate them.

As global land-use patterns will have to adapt to climate change, the potential for optimizing these patterns by matching the different land-use categories to the needs of heterogeneous potentials have to be considered. There are and will be regions that are especially appropriate for certain land-use types, e.g. because of their favourable climatic conditions or fertile soils. Urban areas, for example, often spread on fertile land even though they do not require them, outcompeting agricultural or forestry systems that do depend on fertile soils. The Sahara region, on the other hand, is of little use for agriculture, but is suitable for solar power harvesting, potentially combined with desalination of water along the coastlines. This, however, requires large investments to install the infrastructure for power generation and for electricity transport to the regions with high energy demand – such as Europe. Joint international efforts, like the recently launched DESERTEC project, could lead the way to the benefit of all. In the interest of climate mitigation, adaptation, and development, international efforts are needed to harmonize the spatial patterns of land use with the spatial patterns of potentials, beyond national boundaries and interests.

Global Agricultural Commons: A Proposal

'Global Agricultural Commons' may provide a way to overcome the inefficient use of land resources. Under such a scheme the most fertile areas of the planet would be declared a global public good (albeit still part of the national territories) and reserved for agricultural production. Wealthier regions increasingly expect countries like Brazil, Indonesia, and the Congo to refrain from large-scale deforestation or timber harvest and protect the global public goods and services that tropical rainforests provide to humankind. Could these countries in return expect other countries to put their productive agricultural systems to the most valuable and yet sustainable use to feed the world? Declaring the fertile soils of the Earth a common agricultural good would help to frame the supranational obligation to use them efficiently and sustainably.

The idea of conserving areas of international interest is not new: the UNESCO's 'Convention concerning the Protection of the World Cultural and Natural Heritage' and its *International Union for Nature*

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Conservation (IUCN) already provide frameworks for the protection of areas of universal value. Intensive but sustainable exploitation of the agricultural production potential is, however, not yet considered a value that deserves internationally coordinated protection.

There are of course several restrictions to the idea of globally optimized land-use patterns and agricultural commons. First of all, the ecological side effects will have to be carefully evaluated. Land conversion often triggers undesired secondary effects, such as carbon emissions, degradation, or increased vulnerability to climate variability. Intensive agricultural management often comprises non-sustainable treatment of soils and water as well as spillover of nutrients and pesticides to neighbouring ecosystems and also causes emissions of nitrous oxide and methane, both being very potent greenhouse gases. These systems have high energy requirements for providing production inputs, like fertilizers, pesticides, and machinery. An optimized global land-use pattern will require more trade and transportation between the producing and the consuming regions.

There are, certainly, also many political obstacles, the most important being the lack of international trust. The supply of fundamental resources to sustain human livelihoods, like water, food, and energy, is usually considered a question of national autonomy. Not surprisingly, the most protectionist policies are prevalent in the agricultural and energy sectors. Relying on international trade for providing a larger share of domestic food supplies would require the development of strong and competitive non-agricultural sectors, which is an obstacle for many food-insecure countries.

Yet, in a world that faces the risk of dangerous climate change and the enormous challenge to guarantee a decent life for 9–12 billion people these political obstacles may have to be overcome. Planet Earth, a number of degrees Celsius warmer than today, is unlikely – if not by all means incapable – of carrying such a big human population. Rising up to the double challenge of climate change and population growth seems impossible without calling into question the current land-use pattern, which has emerged from a history that was more or less blind to considerations of global sustainability.

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