Trade-offs between environment and livelihoods: Bridging the global land use and food security discussions

Patrick Meyfroidt

F.R.S. - FNRS, 1000 Brussels, Belgium & Université catholique de Louvain, Earth and Life Institute, Georges Lemaître Centre for Earth and Climate Research (TECLIM), 1348 Louvain-La-Neuve, Belgium

Submitted to Global Food Security, 7 February 2017
Accepted for Global Food Security, 4 August 2017

Citation:
Meyfroidt P. (2017) Trade-offs between environment and livelihoods: Bridging the global land use and food security discussions. *Global Food Security*, in press, https://doi.org/10.1016/j.gfs.2017.08.001.

Abstract:
This paper connects the discussion on the trade-offs between agricultural production and environmental concerns, including the asserted need for global land use expansion; and the issues of rural livelihoods and food security. Several widespread narratives are challenged. The key insights are: 1/ There is a severe research gap about how concrete interventions can reduce the need for agricultural expansion through changing consumption. 2/ Increasing global food production can hardly be achieved without environmental trade-offs. 3/ The food security / environment trade-offs can be mitigated by recognizing that some supply chains benefit little to food security, while entailing high environmental impacts such as deforestation. 4/ Through prices, global food production is linked to food security of the - mainly urban - low income, net food buyers. 5/ Developing commercial farming, including medium-scale farms providing high labor productivity employment, can contribute to food security through rural wages. 6/ Developing such value chains based on commodities with high income- and price-elasticity of demand requires interventions to avoid deforestation through a rebound-effect.

1. Introduction

Land use, in particular agriculture, is fundamental in ensuring food security. But land is also a nexus for crucial environmental challenges such as land degradation, biodiversity loss, climate change, and provision of multiple ecosystem services. Land use expansion into natural ecosystems, such as through deforestation, plays a critical aspect in these impacts. Identifying solutions to achieve sustainable land uses requires to understand the complex trade-offs and synergies associated with different trajectories of land systems change.
The paper revisits two contrasting rationales. The first argues that the global environmental and food security challenges are directly linked together through the volume of global production, hence assuming that food production for urban middle-class demand is directly substitutable with food security for the undernourished. The second rationale argues that there are little trade-offs between environmental conservation and food

security, as the global food supply is already adequate and environmental degradation such as through deforestation for agricultural expansion essentially serves the demands of a wealthy middle-class. This paper argues that although there are elements of truth in each of these rationales, they also insufficiently reflect the complexity of the interactions between environmental conservation, global food production and food security.

The paper reconnects two related but too often disconnected lines of inquiry: On the one hand, the discussion on land use change, addressing the issues of trade-offs between agricultural production and environmental concerns and of the asserted need for global land use expansion over the coming decades; and on the other hand, the issues of rural livelihoods and food security as explored mainly from the local perspective, in particular from agricultural economics. Reaching across these fields is necessary to begin to untangle the complex interactions between environmental conservation, global food production and food security, although this paper is only one step in this necessary dialogue.

The paper is organized by following a series of questions. First, do we need to increase global agricultural (or food) production at the 2050 horizon? I will start with the mainstream projections of global food demand, and then distill the key outputs from the works exploring the option space for managing this demand. Second, based on this global demand, is there a need for agricultural expansion, and are there ways to achieve such expansion with low social and environmental costs? Third, what are the links between these debates about global food production and the issue of food security in rural and urban areas of the developing world? Fourth, how is it possible to channel agriculture for income and food security while managing the trade-offs and synergies with environmental issues related to land use change and agricultural expansion?

2. Prospects for global food demand and option space

The debate on the need to increase global food production over the coming decades is often obscured because of unsourced numbers and the lack of disclosure of underlying assumptions. Highly cited sources assert a need for a 100–110% increase in global crop demand from 2005 to 2050, based on extrapolations of the relations between per capita demand for crops and per capita real income since 1960 (Tilman et al. 2011). Others argue forcibly that the world already produces enough food to feed 9-10 billion people, the population expected by 2050 (Holt-Giménez et al. 2012). These conflicting statements deserve further scrutiny. I will focus here only on calories, as one issue with solid data, although the other dimensions of nutrition security are increasingly highlighted.

Over 2013-2015, based on the Food and Agriculture Organization (FAO) data, the global average food consumption was 2891 kilocalories per capita per day (kcal cap^{-1} d^{-1}) (FAO 2016). The global Average Dietary Energy Requirement (ADER), which is a measure of the calories needed based on the demographic structure (gender, age) and level of physical activity of the World's population, was 2353 kcal cap^{-1} d^{-1} (FAO 2016). Currently, we thus indeed produce enough food for the global needs. The 2050 prospects are different. For 9.7 billion people as forecasted in 2050 (United Nations 2015), the 2015 agricultural production would translate into an average food consumption of 2153 kcal cap^{-1} d^{-1}, clearly below the 2015 ADER. In addition, the global ADER is expected to increase slightly due to a decreased proportion of children in the global population. FAO projections based on demographic (based on a previous projection of global population of 9.15 billion people in 2050), income and supply-side trends forecasted not a doubling, but a +43% increase in calories production, corresponding to a +50% of cereals production and a +60% of overall crop production, and a consumption of 3070 kcal cap^{-1} d^{-1} (Alexandratos and Bruinsma 2012). This FAO projected increase considered that 400 million people would still be suffering from an insufficient calories intake. The main drivers of increasing food demand are population and income growth. Accordingly, food consumption is not expected to increase significantly in high income economies. Much of the growth is expected to occur from developing and emerging economies, with a relatively stronger role of population growth in Sub-Saharan Africa and Latin America, and of income growth in Asia (Hertel and Baldos 2015). Overall, the emerging urban middle-class in developing economies will drive the major share of food demand increases.

The disagreement between opposite visions on the need for increasing food production relies essentially on assumptions about possible changes in consumption regimes. Beyond incomes, changes in consumers tastes and regional diets composition can strongly influence future food demand (Le Mouël et al. 2016). One major trend observed e.g. in Asia is the Westernization of diets, with reduced per capita consumption of rice, and increased consumption per capita of wheat and wheat based products; high protein and energy dense food; temperate zone products and convenience food and beverages (Pingali 2006). Whether there are ways to reduce the overall demand for food by modifying diets or other aspects of food management is thus a central question. Many works have explored this option space, often with a focus on animal products consumption, and even more specifically ruminant meat (Kastner et al. 2012, Bajzelj et al. 2014, Hedenus et al. 2014). Animal feed production uses about 560 Mha, or about 40% of the global arable land, including 220 Mha for cereal grains, 66 Mha for cereal and legume silage and fodder beets, 131 Mha for oil seed cakes, and 126 Mha for crop residues (Mottet et al. 2017). Cassidy et al. (2013) estimated that 36% of the calories produced for the main 41 crops were used for animal feed, of which 89% were consumed in the production process, leaving only 4% of crop-produced calories available to humans as animal products. Another 9% of crop-produced calories were used for industrial uses and biofuels. Shifting all these crop calories to direct human food consumption would allow a +70% increase in calories availability. Combining different diets scenarios with varying richness in calories, in overall animal products and in the share of ruminant versus monogastric sources in the latter, Erb et al. (2016) estimated that the total biomass harvest necessary in 2050 could range from 6.7–19.9 gigatons of dry matter per year (Gt dm y^{-1}), thus covering a range from 1 to 3. Expressed in these units, the total biomass harvest amounted to 10.2 Gt dm y^{-1} in 2000 and the FAO projection for 2050 amounts to around 13 Gt dm y^{-1}. The most extreme scenarios, with a global vegan diet or a vegetarian diet relying on monogastric species for animal products (eggs) would require a global biomass harvest of 6.7–12.4 Gt dm y^{-1}, depending on yields and land use change assumptions. Yet, although substituting animal products consumption appears more efficient in terms of calories, more nuanced analyses emphasized the importance of meat in global protein supply, showing that on average 1.3 kg of protein from human edible feed was required per kg of meat protein produced, although with large diversity ranging from 0.1-0.5 kg edible protein / kg meat protein produced in extensive grazing and backyard monogastric production systems to 4.1-5.2 in industrial systems (Mottet et al. 2017). Optimizing meat production systems first requires to better identify the ways to minimize competition with direct human consumption of plants. Other transformative scenarios are the replacement of meat products by insects, cultured meat or imitation meat, which could potentially reduce agricultural land demand by up to 38% based on current consumption levels of 2011, assuming a 50% replacement of meat products by these substitutes (Alexander et al. 2017).

Yet, we are still severely lacking of knowledge on how to actually change diets, and especially what are the realistic prospects for reducing meat consumption. A handful of studies have used demand elasticities to price changes to explore the effects of a carbon tax on meat or animal products consumption, with unclear results. A tax of 60 EUR / ton of CO_2 equivalent (tCO_2eq) in the European Union could reduce overall meat consumption by 1% (a decrease in ruminant meat consumption by 15% being compensated by a 1% and 7% increase in that of pork and poultry, respectively), and land use demand for pasture by around 12 Mha and for cropland by around 4 Mha (Wirsenius et al. 2011). Another study estimated that a tax of 80 $ / tCO_2eq in developed economies would reduce meat consumption by only 5% (Revell 2015). In a study for Denmark covering all food products, the most efficient scenario estimated a reduction in calories consumption of 1.2–6.1% for a cost of around 20–230 EUR / tCO_2eq (Edjabou and Smed 2013). Overall, a review of studies exploring the potential for taxes and subsidies to influence diets for health purposes suggested that the effects were generally modest (Clark et al. 2014, Garnett et al. 2015), but it is unclear how these results translate into calories or meat consumption. Further, these taxes are often considered as regressive – i.e., having a stronger impact on low-income groups than on high-income groups. Health and nutrition studies show that food-related behaviors are also influenced by factors other than prices, such as habits, or taste, trustworthiness and convenience of different foods (Garnett et al. 2015). Beyond regulations directly aimed at incentivizing choices, many other policy levers have been proposed to influence consumption choices, ranging from changing the broader context of food systems through regulatory governance and supporting collaboration and shared agreements, to information, education, and promotion through community initiatives, labelling and other means (Garnett et al. 2015). But even less data is available on the potential effectiveness of these tools than for taxes. In addition, studies point to complex effects, with some measures aimed at reducing the intake of some kinds of food resulting in substitution effects increasing the intake of other food, with patterns difficult to predict (Garnett et al. 2015). Prospects for spontaneous changes in diets related to cultural shifts towards postmaterialist values with increasing living standards are unconvincing either: An inflection point in meat consumption has been identified for annual incomes around 36,000 USD (Cole and McCoskey 2013) or ranging between 35,000–53,000 USD per capita (Vranken et al. 2014), against a global GDP cap^{-1} ranging around 10,000 USD in 2015, expressed in constant 2010 USD. Waste reduction is also frequently mentioned as representing a large potential, but virtually no study quantified the concrete waste reduction that could be achieved by applying a determined policy measure (though see zu Ermgassen et al. 2016). Further, scenarios of consumption shifts are typically built at the global scale. Although at the horizon 2050 developed countries are expected to continue to consume more food per capita than developing countries, the latter will constitute the overwhelming majority of food consumption globally (e.g., 82% of world's calories consumption in the FAO projections, Alexandratos and Bruinsma 2012). Hence, any strategy that aims to have a significant impact on food demand cannot be restricted to high income countries, but has to also affect consumption of the incoming urban middle-class in emerging countries, which may pose significantly stronger challenges including on the political level.

3. Agricultural expansion, potentially available cropland, and trade-offs with intensification

Consistent with the prospects for increasing agricultural production, the requirements for agricultural expansion are uncertain, but likely important. The FAO projections described above, which account for a +60% in overall crop production, would lead to an increase in +69 Mha of arable and permanent cropland globally from 2005 to 2050, or a ~+4.7% increase. Although this estimate has often been deemed excessively alarmist, it is in the lower end of the published estimates forecasted by a range of economic and integrated assessment models over a range of scenarios, whose mean is +20%, or ~310 Mha from 2006 to 2050 (Hertel et al. 2016). The estimate depends of course on the evolution of demand and diets as discussed above, as well as on prospects for intensification. The range of +4.7–+20% corresponds to 1.5–6.9 Mha y^{-1}, leading Hertel et al. (2016) to conclude that global cropland conversion might continue at roughly the same rate as over 1961–2006, i.e. ~4 Mha y^{-1}. Projections for grazing land are even more uncertain, with estimates ranging from +0–151 Mha over 2000–2030 (Lambin and Meyfroidt 2014). Grazing land demand strongly interacts with that for cropland through assumptions on livestock production systems.

Are there ways to achieve such agricultural expansion with low environmental costs? First, it depends on the rate of gross versus net changes. In the FAO projections, as in most estimates, the net change results from a contraction of cropland in developed countries and an even larger expansion in developing countries, here +107 Mha or 2.4 Mha y^{-1}. Over 2000–2012, a net global agricultural land contraction of -5.4 Mha y^{-1} (accounting for both cropland and pastures) was accompanied by gross and net rates of tree cover loss of respectively -19.2 and -12.5 Mha y^{-1} (Hansen et al. 2013). So even lowering the net rate of expansion is in itself insufficient to conserve natural areas, and trends in developed countries influence what happens elsewhere. Second, policy-makers and other actors have been increasingly trying to direct agricultural expansion towards what has been called "potentially available cropland" (PAC), i.e. land moderately to highly productive under rainfed farming with limited investments, and that is currently neither under intensive use, legally protected, or under intact mature forest cover (Lambin et al. 2013). However, recent assessments have shown that such land is scarcer or less easy to cultivate than generally expected, and that even without being forested it may entail important social and environmental trade-offs. The Southern African woodlands and savannas are often regarded as a large source of PAC, in particular for soybean expansion. Under an optimal land use planning in terms of carbon efficiency, about 76.4 Mha of land in that region could be productive for soybean with a carbon trade-off between 2 and 6 tC per annual ton of soy under intensive farming (Gasparri et al. 2016). Although this favorably compares to a global average trade-off of ~40 tC t^{-1}.y on current soybean land (Searchinger et al. 2015), using these lands to achieve the increase in soybean production of +148 Mt projected by the FAO would entail 157.7–922.7 Mt of C emissions, and potentially large biodiversity and social impacts (Gasparri et al. 2016). Another region deemed to hold significant PAC is the Former Soviet Union, with vast amounts of land abandoned in the aftermath of the Soviet Union collapse. Yet, of the 47.3 Mha that were lying idle across Russia, Ukraine and Kazakhstan in 2009, only 8.5 Mha could be considered as productive and recultivable without massive infrastructures investments or socio-economic revitalization policies, and with low environmental costs (Meyfroidt et al. 2016). The wheat production potential on these lands would represent 14.3 (9.6–19.5) Mt y^{-1}, or ~6% of the FAO-projected additional demand for 2050. A prominent report estimated around 445 Mha of PAC (Deininger et al. 2011), but analyses in several key regions suggested that not more than 31% of the identified land could be cultivated without having to overcome strong constraints and with relatively low – though not inexistent - social and environmental trade-offs (Lambin et al. 2013). Further, food production is only one of several land uses that are competing for accessible and productive lands. Urbanization, intensive forestry and bioenergy production could together represent an additional demand for land of 166–380 Mha over 2000–2030 (Lambin and Meyfroidt 2014).

This suggests a very limited scope for agricultural expansion with low environmental impacts. Minimizing environmental impacts would thus require restricting agricultural expansion. Intensification is another major way through which food production has increased historically, and potentially, future increases in yields could be large. Currently, yields in the major irrigated wheat, rice, and maize systems in developed countries reach ~80% of the potential, but average yields in developing countries, in particular in rainfed systems are commonly 50% or less of yield potential (Lobell et al. 2009, Fischer et al. 2014). Improved information on environmental conditions, such as climate, and markets could raise that level. Improving nutrient and water management can contribute to close the yield gap (Mueller et al. 2012). Closing the yield gap to 100% of currently attainable yields per crop and climatic zone would increase production by 45-70% for the seventeen major crops. Doubling production of maize, rice, wheat and soybean for 2050 without expansion would require a ∼2.4% y^{-1} linear rate of yield gains, while the recent global average rates of yield increase for these four crops were ranging between 0.9 and 1.6% y^{-1} (Ray et al. 2013). For the period 1991–2010, yield increase has been strongly linear: Expressed as a percentage of the estimated yield in the last year of the series (2010), the relative rates of gain were 1.0% y^{-1} for wheat, rice and soybean, and 1.5% y^{-1} for maize (Fischer et al. 2014). These linear trajectories means that the relative rate of gain decreased over time (Grassini et al. 2013). Sustaining the current rates would allow an increase of ∼67%, ∼42%, ∼38%, and ∼55% in maize, rice, wheat and soybean production, respectively, by 2050. This would be roughly in line with the FAO projected increase in cereals demand. Yet, it is unclear that even current rates of yields increases can be sustained. Indeed, although massive increases in yields have been achieved over the last fifty years in most parts of the World, yields either never improved, stagnated or collapsed across 24–39% of maize-, rice-, wheat- and soybean-growing areas, in particular Sub-Saharan Africa, some parts of India and China, and Mexico for maize and rice, and many regions of Europe, India, China and Australia for wheat (Ray et al. 2012). Grassini et al. (2013) found widespread deceleration in the relative rate of increase of average yields of the major cereal crops during the 1990–2010 period in countries with greatest production of these crops, and strong evidence of yield plateaus or an abrupt drop in rate of yield gain in 44% of the cases, which, together, account for 31% of total global rice, wheat and maize production. For cereals, yields growth rate have declined from ~2.5%/y in the 1980s to less than 1.5%/y in the late 2000s (Alexandratos and Bruinsma 2012). The FAO projections assume a further reduction of the annual rate of yields increases, all crops aggregated, from 1.7% over 1961-2007 to 0.8% over 2005/2007-2050. Intensification along current yields trends would be insufficient for doubling production, which would require an extra expansion of 219 Mha only for maize, rice, wheat and soybean (Ray et al. 2013). These estimates are based mostly on continuing developments and application of mainstream agricultural technologies based on improved seed varieties and pest, nutrient and water management. More disruptive technologies to increase yields as well as to reduce the environmental impacts of intensive agriculture have been proposed, such as increasing the diffusion of genetically engineered (GE) crops which currently cover ~ 10% of rainfed cropland globally (Lemaux 2009). Yet, the socio-economic implications for farmers to adopt GE crops are very variable and depend on many features of the broader economic and institutional environment (Lea 2008). These studies provide useful diagnostics of the situation and trends in yields, as well as on the potential that can be achieved through a reduction of the yield gap, but in themselves, they cannot ensure that intensification will suffice to reach food demand without expansion.

Further, intensification may come with its own environmental impacts, in terms of energy and water use, greenhouse gases emissions, biophysical climatic effects, and others. Intensification also interacts with expansion of land use in complex pathways (Meyfroidt et al. 2014). Intensification can lead to a rebound effect – i.e. making the production process more profitable and encouraging further expansion into natural ecosystems, locally or globally –, under conditions that labor force is unconstrained (migration is possible); intensification is capital-driven and capital is mobile; demand for the intensifying commodity is income- and price-elastic – e.g. such as for meat, leisure crops, feed or bioenergy crops such as soy or oil palm, especially with open markets –, and the initial yields in the intensifying region are low relative to trading partners (Hertel et al. 2014, Villoria et al. 2014, Byerlee et al. 2014). With an increasingly integrated agricultural economy, a prospective African Green Revolution is likely to induce net cropland expansion, deforestation and increasing carbon emissions, both globally and in Africa (Hertel et al. 2014). Locally, intensification may occur through the expansion of a high-yielding commodity crop into lower-productivity agricultural land or natural lands, possibly displacing the more extensive production further into forest (Meyfroidt et al. 2013, 2014).

4. Linkages between global food production, environmental tradeoffs, and local food security

This section returns to the links between global agricultural production and its environmental impacts, and food security. A first line of reasoning starts by the well-established lack of a direct connection between increasing global food production and improving food security, considering that the latter is predominantly an issue of accessibility of food and of poverty, rooted in multiple factors including income inequalities (Fan and Brzeska 2016). Further, deforestation is increasingly driven by urban population growth and agricultural trade (DeFries et al. 2010), with large-scale capitalized enterprises playing an increasingly important role (le Polain de Waroux et al. 2016). The major products that are rapidly expanding and causing most of the deforestation are essentially a set of commodities with high income- and price-elasticity of demand, including beef, oil and sugar crops and animal feeds such as soybean and oil palm, leisure crops like coffee and cocoa, and other industrial crops like rubber (Rueda and Lambin 2014, Henders et al. 2015). Along this line of reasoning, as these commodities essentially support the diets of urban and middle-class people in developed and emerging countries, there is in reality no strong trade-off between environment and food security. Deforestation for increasing beef and cash crops production could easily be foregone without harming food security, and the main approach to eliminate deforestation is to focus on "cleaning" the supply chains of a set of key major "forest-risk" commodities that link production landscapes to wealthy consumers through large-scale agribusiness companies (e.g. see https://www.worldwildlife.org/initiatives/transforming-business).

This line of reasoning builds on valid points but is in itself insufficient to account for the more complex linkages between land use and food security. First, it fails to consider that net changes in land use areas at the global scale are an imperfect indicator of the actual dynamics and impacts of land use. Then, the above reasoning obliterates two key linkages between food production for the middle-class, land use changes, and food security of the undernourished, affecting two different categories of food insecure populations: through middle-class demand as competing with demand from the poor urban or landless net food buyers, and through middle-class demand as providing a potential income source for rural producers.

First, on net, the area of the crops that constitute the major staples for food insecure households, in particular cereals, roots and tubers, has been rather stable over the recent decades at global level, but this hides significant gross changes, with contraction of farmland in developed countries (Rudel et al. 2009), as well as massive abandonment of cereal croplands with the collapse of the Soviet Union (Schierhorn et al. 2013). At the regional level, harvested areas of cereals have been stagnant in Southern Asia and South and Central America since the 1980s, but still expanded almost linearly by ~1.5 Mha y^{-1} in Africa and 0.45 Mha y^{-1} in Southeast Asia over 1980-2014 (FAOSTAT 2017), corresponding to annual growth rates (not compounded) of respectively 2.4 % y^{-1} and 1.0 % y^{-1}. Roots and tubers harvested areas expanded by ~0.65 Mha y^{-1} in Africa over the same period, thus with an annual growth rate of 6.1 % y^{-1}. Even this masks important gross changes linked to spatial redistribution within regions. Expansion of staple food crops remains a major challenge in regions with growing rural farming populations. Globally, whereas from 1980 through 2000 increased food demand was essentially met by increases in crop yields on existing farmland, since 2002 more than 25% of the increase in demand for staple food crops has come from increase in harvested crop area (Grassini et al. 2013).

Second, with continuing increases in demand for agricultural products but also continuing increases in agricultural productivity, prices may resume their long-term declining trend, but this would require continuing expansion (Fischer et al. 2014, Baldos and Hertel, 2016, Hertel et al. 2016, see above). Hence, strong restrictions on land supply for environmental conservation may well contribute to prices increases. Indeed, as seen above, with current yields trends staple crops expansion may still be required, depending of the necessary increase (around +50% or +100%) in production. Further, as agricultural markets are not fully integrated and protectionist behaviors have been rising recently, local prices may increase in countries or regions with restrictions on expansion even if the global ones are stable. Increasing use of cereals for animal feed and biofuels also create possible linkages between stronger demand from middle-class, tensions on land use and prices of staple food. High food prices negatively affect the food security of those households which are net food buyers, which are mainly urban households, rural off-farm laborers and the almost landless rural ultra-poor who fail to produce sufficient food (Swinnen and Squicciarini 2012, Hertel 2016). Urban households are a growing category of the poor and food insecure in a series of countries (Hertel 2016). The impacts of changing food prices on food security depend on the different commodities affected, but with increasing market integration and substitutability in commodities, food insecure households can be affected by changes in prices of commodities they don’t typically consume. The growing number of urban and rural non-farm food insecure households tends to be neglected in many advocacy discourses about food prices and the future of farms, such as the Food Sovereignty discourses (Jansen 2015).

On the other hand, notwithstanding the relative rise of urban food insecurity, a large share of food-insecure households are still farmers. Agricultural growth and development constitutes a crucial way to increase real income and decrease poverty for this category, which itself is strongly related to food security. Agricultural growth has been shown to be able to deliver up to three times more pro-poor effects than general growth, provided targeted strategies for different households categories (market participants, market entrants, subsistence-oriented) (de Janvry and Sadoulet 2010). For the ultra-poor farming households completely disconnected from both agricultural markets and off-farm opportunities, staple crops intensification remains the key priority (Barrett 2014, Jayne et al. 2014a,b). But a growing share of farmers sells at least part of their harvest on markets. Small farmers are involved or sometimes dominant in some of the commodity crops most associated with deforestation, such as coffee, cocoa, rubber, oil palm, and others (Byerlee 2014, Naylor 2016). High food prices are favorable for the net food sellers, mainly rural farming households, who can thereby benefit from higher income streams. Wage laborers in agriculture may be affected in ambivalent ways, and the effects of prices on food security are also time-dependent. Over the short term, price increases can have deleterious effects on poverty rates and thus food security, but over the medium term, price increases may lead to a reduction of poverty levels, essentially through their impact on rural agricultural wages, and to a lesser extent through inducing a supply response (producers are incentivized to produce more, and the additional supply corrects the price downwards) (Ivanic and Martin 2014, Martin and Ivanic 2016). Overall, the evidence suggests that to improve food security and reduce poverty, yields increases have to be accompanied by increases in labor productivity that raise farmers income and laborer's wages (De Janvry and Sadoulet 2010). Increase in agricultural labor productivity indeed has a more significant direct effect on poverty reduction than increase in total factor productivity. Yet, when such increase is too rapid it creates excess labor force (De Janvry and Sadoulet 2010). The appropriate balance depends at least on two factors: The context-dependent labor force absorption capacity in the off-farm economy, which in many developing regions appears limited, suggesting that a too rapid mechanization would fail to pull laborers out of poverty (Li 2011); and the pro-poor effects of agricultural development through linkages with other sectors.

Farmers are often equated with "smallholders", with the literature often framed in a dichotomy of smallholders versus large-scale, capitalized corporate farming (Byerlee 2014). Yet, this obscures the emergence of a category of medium-scale, commercial-oriented farmers, which have larger farms than the typical smallholders. What constitutes a medium-scale farmer is context-dependent, and as an emerging category its boundaries remain fuzzy, but a threshold of 5 ha of agricultural lands is often used to distinguish them from smallholders, and they are generally considered to be up to 100 ha (Samberg et al. 2016, Jayne et al. 2016). These medium-scale farmers constitute a heterogeneous group with different origins, from smallholders slowly consolidating land by acquiring their neighbors plots to urban elites investing some of their income to acquire farmland in the countryside, often hiring a professional farm operator. The dynamics and outcomes strongly differ across regions and countries, pointing either to further reduction in average farm size, or to a consolidation, with manifold prospects (Jayne et al. 2016).

In conclusion, cash crop production, linked to deforestation, can thus generate income for poor households and play a role in food security. At this level, there are thus trade-offs between environmental conservation and food security, even if the crops that cause deforestation are not eaten by food insecure households.

5. Channelling agricultural development for livelihoods and food security while managing environmental trade-offs

The question then is what forms of agricultural development can improve income and food security, and achieve the delicate balance between raising income for a large group of rural producers and securing food provision for an increasingly urban and middle class population, while minimizing environmental impacts of land use. This debate is often reduced to simplistic narratives on the future of farms, food security and smallholders, from visions relying massively on large-scale mechanized farming combined with accelerated economic development to pull smallholders out of agriculture, and reconcile food production with preservation of natural habitats (Nordhaus et al. 2015), to the most extreme agroecological propositions of small-scale, labor-intensive farming that support autonomous peasant communities fully independent of external inputs and of commercial relations (Altieri 2009).

Large-scale farming can play a role in increasing food production for urban and distant consumers, but its contribution to local food security and pro-poor economic development appears often limited. Positive spillovers can arise from the coexistence of large-scale and smallholder farming (Deininger and Xia 2016) or their interactions such as through outgrowers schemes (Herrmann 2017), but large-scale investments often result in smallholders' marginalization (Oberlack et al. 2016), leaving them with little prospects outside agriculture due to the limited absorption capacity of other sectors of the economy (Li 2011). Large-scale plantations also often require a tailored policy context to thrive against smallholders (Byerlee 2014).

Smallholders, on the other hand, play a central role in current agricultural production, with 70% of the food calories in Latin America, sub-Saharan Africa, and South and East Asia produced in likely smallholder-dominated areas (with an average farm size of 5 ha or less), which encompass ~383 million households (Samberg et al. 2016). But with increasing farming population density and farm sizes decreasing below one hectare, tiny farms in many places become net food buyers. Scarcity of available, productive land is already a reality in some areas: In several African countries, the bottom 25% of smallholder households control less than 0.12 ha per capita, and a notable share of young men and women start their families without inheriting land (Jayne et al. 2014b). This pressure on land does not only arises from population growth and physical scarcity of productive land, but also from legacies of colonial segregation between "customary" and "state" lands, the prior history of public investments, the clustering of population and usufruct land tenure. Policies governing access to land can thus play a crucial role to support smallholders, as for small farms, a very small incremental addition to land access is associated with a large relative rise in income (Jayne et al. 2014b).

Yet, a sole focus on smallholders appears insufficient to address the needs for increasing land and labor productivity. Below certain farm sizes, diminishing returns for land and capital inputs appear, making it increasingly difficult for small farmers to ensure their food self-sufficiency (Jayne et al. 2014a,b, 2016). Very small farms appear hindered in accessing commercial supply chains due to a lack of entrepreneurial capacities and assets for risk-taking behaviors, and to the logistics of marketing (Barrett 2008, Neven et al. 2009, Collier and Dercon 2014). This suggests a complementary role to play for emerging medium-scale commercial farmers to provide employment, food security, and poverty reduction. This group of farmers may be able to foster labor productivity growth by affording the necessary capital inputs, to provide wage labor income, and to achieve integration in retail value chains towards domestic and export markets, such as evidenced in Thailand (Morris et al. 2009), Kenya (Neven et al. 2009), Senegal (Maertens et al. 2009, Maertens et al. 2012), Mozambique (Smart and Hanlon 2014), or Indonesia (Falcon 2014). Medium-scale farmers appear particularly able to reap the benefits of inputs or outputs prices support programs (Jayne et al. 2014b). In some contexts, these medium-scale farmers may increase labor productivity more than small farms, while providing more jobs per hectare than large-scale enterprises, thus achieving a balance between environmental efficiency and livelihoods (Baumert and Nhantumbo 2017), though this constitutes an active research topic. The emergence of medium-scale farms, though, can also correspond to forms of local land grabbing and elite capture of land resources with little benefits for rural households.

Both smallholders and medium-scale farmers engaged in commercial activities contribute to the production of domestic, staple crops which are a direct input to food security, but also to the production of commodities for middle-class and high income market segments domestically and abroad, including luxury and leisure crops, feed crops for animals and bioenergy, and others. These commodities can thus contribute importantly to food security indirectly by supporting the livelihoods of farming and wage laborers' households, depending on the contexts and conditions under which these supply and value chains are organized (Naylor 2016). As seen above, these high income and price-elasticity crops, which offer potential for profitable value chains, also constitute the major source of deforestation. Several approaches can contribute to mitigate this trade-off: agricultural intensification, or improving value chains, coupled with land use policies, as well as more nature-friendly forms of agricultural intensification. Agricultural intensification can contribute to spare land for conservation of natural ecosystems and allow for land restoration especially under certain conditions, i.e. when (i) intensification is based on labor inputs and there are strong constraints on increasing labor force; (ii) the expansion potential of the intensifying crop is limited, due to biophysical constraints, land use policies or other factors; and (iii) the demand for this crop is rather inelastic, the typical example being staple crops in closed markets (Hertel et al. 2014, Villoria et al. 2014, Byerlee et al. 2014). Intensification of staple crops can thus more easily result in land sparing, as exemplified in Vietnam with paddy rice and maize intensification, the former being very constrained spatially in mountains due to limited availability of flat lands and irrigation water (Meyfroidt and Lambin 2008). In contrast, intensification of commodity crops is more likely to result in a rebound-effect. The rebound effect of export-oriented agriculture can be local or global, i.e., it can result in increased agricultural expansion in the intensifying regions but with a net land sparing at global scale through redistribution of agriculture in the most suitable locations, or it can actually result in net expansion of the global agricultural land base (Hertel et al. 2014, Kastner et al. 2014, Jadin et al. 2016). Switching to high value crops, gaining access to domestic and international retail markets, as well as value chains interventions such as certification schemes can also contribute to increase the share of added value that reaches farmers and wage laborers or to other benefits (Neven et al. 2009, Maertens et al. 2009, Smart and Hanlon 2014). These different interventions to increase income have to be accompanied by other interventions to control land use expansion, in order to neutralize potential rebound effects and achieve land sparing, and channel residual expansion towards land with the most favorable trade-offs (Furumo and Aide 2017). These interventions can range from land zoning policies (Bruggeman et al. 2015) to supply chains interventions (Rueda et al. 2017). Improving transparency in supply chains is a prerequisite for analyzing value chains and assessing how to simultaneously increase the share of value that reaches to farmers and control deforestation (Godar et al. 2016). Other authors argued that diverse forms of tree-based or nature-friendly land use intensification through agroforestry and agroecology schemes could also mitigate the trade-offs between agriculture and environmental goals (Fischer et al. 2017a, Hecht et al. 2014). The main advantage of these land use systems is that the food and ecosystem services produced are more likely to directly benefit to local, food insecure populations (Fischer et al. 2017b). These multifunctional landscapes could also be supported by insertion into international commodity supply chains through the development of standards or other forms of payments for the environmental services provided by these landscapes and land uses (Rueda et al. 2015, Börner et al. 2017). Yet, important uncertainties remain on how to scale up these approaches, e.g. in terms of the additional labor requirements that these systems have, as evidenced by the limited adoption of these practices by farmers.

Overall, with a myriad of land users spread over multiple jurisdictions, and complex international supply chains, implementing these different approaches constitutes a real challenge. This requires coalitions of public and private actors whose objectives can align to develop supply chains interventions and territorial trans-scalar land use planning processes that incorporate actors and stakes across scales in order to make these trade-offs between local livelihoods and global challenges apparent (Lambin et al. 2014, Rudel and Meyfroidt 2014).

6. Conclusions

This article explores some of the linkages between several key sustainability issues, i.e. the global and local trade-offs between agricultural production and environmental concerns, the asserted need for global land use expansion over the coming decades, and the pathways towards improving rural livelihoods and food security especially for farming households. Exploring these linkages is crucial to move beyond simple narratives which either equate global food production to food security or complete disconnect these two issues.

Scenario-based studies show that there is a large option space for reducing the additional demand for agricultural production and land use, in particular through changes in consumption regimes. On the one hand, based on the projected dietary regimes, meeting the caloric requirements of the World's population requires to significantly increase global food production for 2050. The +60% increase in crop production for 2050 projected by FAO falls in the middle range compared to the more extreme scenarios of doubling food production and of transformative shifts in diets e.g. towards vegetarianism. Retrospective assessments have shown previous similar FAO projections to be sufficiently accurate (Hertel et al. 2016), so they may thus appear as a reasonable benchmark. On the other hand, assuming drastic changes in consumption modes, we already produce enough food for the World's population needs in 2050. Considering the challenges ahead, the demand of the global urban middle class should also be considered as one aspect, along with others, on which to intervene. Yet, although many policy levers have been proposed to influence consumption choices, there is a severe lack of knowledge about how far and at what costs the concrete practical options can lead us in terms of changing demand. A focused research effort is required to improve the understanding of how to navigate this option space, as well as on the ethical, cultural and political implications. In the current knowledge situation, we cannot formulate realistic expectations about the possible contribution from demand-side measures, and thus cannot simply dismiss the projected need for increasing agricultural production.

A net additional demand for cropland of ~+70 Mha for 2050, translating into a +107 Mha in developing countries, is on the lower range of the projections under current trends of consumption and intensification. Even if we reduce the net global additional cropland demand, the gross changes could have important impacts. Food production is only one of the multiple land uses for which demand is increasing and which are competing for productive and accessible land. Productive land has to be considered as an increasingly scarce resource, with very little land available for agricultural expansion with small environmental or social trade-offs. Interventions are required to strategically direct agricultural expansion on land that present the most desirable social and environmental trade-offs, as well as to promote sustainable forms of intensification, taking into account the complex linkages between intensification and expansion pathways. Even with optimized allocation of land uses, achieving the global projections of increased agricultural production without environmental impacts would require massive and concerted efforts.

The linkages between this global land use expansion and food security have multiple layers. At first glance, much of the global agricultural expansion and related deforestation over the recent decades is not directly related to food security, as it is not directed towards staple caloric crops eaten by food insecure households, but rather towards a set of commodities with high income- and price-elasticity of demand including beef meat, oil, sugar and leisure crops that mainly support the diets of urban and middle-class households in developed and emerging countries. This suggests that a notable, though unclearly quantified, share of global deforestation can be halted without harming food security of the World's poorest. A key research question is thus to identify what are the types of commodities or supply chains which bring the least contribution to food security but entail highly negative environmental trade-offs (Naylor 2016).

Yet, crucial linkages appear at other levels of analysis. Global food production and local food security are linked through the former's effects on agricultural prices, which themselves affect both food costs and farmers' incomes. There are thus likely trade-offs between environmental concerns linked to global agricultural expansion and the food security of low income, net food buyers households, which form a growing category of the poor in some countries, mainly in urban areas. Further, as the high income- and price-elasticity commodities that drive most agricultural expansion are among those that can allow farmers to enter into international value chains with potentially beneficial effects on their income, land use expansion can thus play a crucial role in food security through income from agricultural activities. This suggests real trade-offs between environmental conservation and food security.

A portfolio approach is required to mitigate these trade-offs. Staple crops intensification for the ultra-poor farming households disconnected from both agricultural markets and off-farm opportunities can improve food security with low risks of environmental degradation through agricultural expansion. But two lessons appear here. First, the limitations of smallholders to engage in high-value supply chains and invest to raise labor and land productivity suggest that developing medium-scale commercial farming is a key complementary path for providing income and employment with sufficiently high labor productivity, which in turn can improve food security. This is not a one size fits all solution, but more research could help understand under which conditions this category of medium-scale commercial farming can provide appropriate balances between yields, labor productivity and a sufficient number of jobs per hectare of farmland. Second, aside from the specific conditions of staple crops with low income and price-elasticity of demand, considering that commercial farming is prone to a rebound-effect, these interventions to intensify or increase farmers' income inevitably need to be accompanied by specific interventions including land use policies and private-led supply chains interventions to minimize their potential environmental impacts.

Acknowledgments
The author is grateful for the invitation to contribute to the IRI THESys Lecture Series at Humboldt University in Berlin in May 2016, which provided the impetus for this article. Very special thanks to Prof. Patrick Hostert for this invitation and encouragements to explore the topics of this article. Thanks to the anonymous reviewers and the Editor, whose comments have helped to strengthen the key points in this paper. All errors and omissions remain mine. This work has received support from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant agreement No 677140 MIDLAND). This paper contributes to the Global Land Programme www.glp.earth .

References

1. Alexander, P., Brown, C., Arneth, A., Dias, C., Finnigan, J., Moran, D., & Rounsevell, M. D. (2017). Could consumption of insects, cultured meat or imitation meat reduce global agricultural land use? *Global Food Security*, in press, http://dx.doi.org/10.1016/j.gfs.2017.04.001
2. Alexandratos, N., Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision. ESA work. Pap, 3. FAO, Rome.

3. Altieri, M. A. (2009). Agroecology, small farms, and food sovereignty. Monthly review, 61(3), 102.
4. Bajželj, B., Richards, K. S., Allwood, J. M., Smith, P., Dennis, J. S., Curmi, E., & Gilligan, C. A. (2014). Importance of food-demand management for climate mitigation. Nature Climate Change, 4(10), 924-929.
5. Baldos, U. L. C., & Hertel, T. W. (2016). Debunking the 'new normal': Why world food prices are expected to resume their long run downward trend. Global Food Security, 8, 27-38.
6. Barrett C. (2014) Assisting the escape from persistent ultra-poverty in rural Africa. In Falcon W. P., Naylor R. L., Frontiers in Food Policy: Perspectives on sub-Saharan Africa. Stanford University's Global Food Policy and Food Security Symposium Series. Center on Food Security and the Environment. Stanford, CA, USA, University of Stanford.
7. Barrett C. B. (2008). Smallholder market participation: Concepts and evidence from eastern and southern Africa. Food policy, 33(4), 299-317.
8. Baumert, S., Nhantumbo, I. (2017) *Small-scale soya farming can outperform large-scale agricultural investments*. IIED Briefing, London, UK.
9. Börner, J., Baylis, K., Corbera, E., Ezzine-de-Blas, D., Honey-Rosés, J., Persson, U. M., & Wunder, S. (2017). The effectiveness of payments for environmental services. *World Development*, *96*, 359-374.
10. Bruggeman, D., Meyfroidt, P., & Lambin, E. F. (2015). Production forests as a conservation tool: Effectiveness of Cameroon's land use zoning policy. Land Use Policy, 42, 151-164.
11. Byerlee, D. (2014). The fall and rise again of plantations in tropical Asia: History repeated? *Land*, 3(3), 574-597.
12. Byerlee, D., Stevenson, J., & Villoria, N. (2014). Does intensification slow crop land expansion or encourage deforestation?. Global Food Security, 3(2), 92-98.
13. Cassidy, E. S., West, P. C., Gerber, J. S., & Foley, J. A. (2013). Redefining agricultural yields: from tonnes to people nourished per hectare. Environmental Research Letters, 8(3), 034015.
14. Clark, J. S., Dittrich, L.O. and Xu, Q. (2014) Empirical evidence of the efficiency and efficacy of fat taxes and thin subsidies. Central European journal of public health. 22(3) p.201-6.
15. Cole, J. R., & McCoskey, S. (2013). Does global meat consumption follow an environmental Kuznets curve?. Sustainability: Science, Practice, & Policy, 9(2).
16. Collier P., Dercon, S. (2014). African Agriculture in 50Years: Smallholders in a Rapidly Changing World?. World development, 63, 92-101.
17. De Janvry, A., & Sadoulet, E. (2010). Agricultural growth and poverty reduction: Additional evidence. *The World Bank Research Observer*, 25: 1-20
18. DeFries, R. S., Rudel, T., Uriarte, M., & Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience*, 3(3), 178-181.
19. Deininger, K., Byerlee, D., Lindsay, J., Norton, A., Selod, H., Stickler, M., 2011. Rising Global Interest in Farm Land: Can It Yield Sustainable and Equitable Benefits? World Bank, Washington, DC.
20. Deininger, K., Xia, F. (2016). Quantifying Spillover Effects from Large Land-based Investment: The Case of Mozambique. World Development, 87, 227-241.
21. Edjabou, L. D., & Smed, S. (2013). The effect of using consumption taxes on foods to promote climate friendly diets–The case of Denmark. Food Policy, 39, 84-96.
22. Erb, K. H., Lauk, C., Kastner, T., Mayer, A., Theurl, M. C., & Haberl, H. (2016). Exploring the biophysical option space for feeding the world without deforestation. Nature communications, 7.
23. Falcon, W. P. (2014). Food security for the poorest billion: Policy lessons from Indonesia. In Naylor, R. L. (Eds) The evolving sphere of food security, Oxford University Press.
24. Fan, S., & Brzeska, J. (2016). Sustainable food security and nutrition: Demystifying conventional beliefs. Global Food Security, 11, 11-16.
25. FAO (2016) Food Security Indicators. http://www.fao.org/economic/ess/ess-fs/ess-fadata/en/#.WJmu-2_hCUk
26. FAOSTAT (2017) FAOSTAT database. http://www.fao.org/faostat/en/
27. Fischer, J., Abson, D. J., Bergsten, A., Collier, N. F., Dorresteijn, I., Hanspach, J., Hylander, K., Schultner, J. & Senbeta, F. (2017a). Reframing the Food–Biodiversity Challenge. *Trends in Ecology & Evolution*, 32(5), 335-345.
28. Fischer, J., Meacham, M., & Queiroz, C. (2017b). A plea for multifunctional landscapes. *Frontiers in Ecology and the Environment*, 15(2), 59-59.
29. Fischer, R. A., Byerlee, D., & Edmeades, G. (2014). Crop yields and global food security. *ACIAR: Canberra, ACT*.

30. Furumo, P. R., & Aide, T. M. (2017). Characterizing commercial oil palm expansion in Latin America: land use change and trade. *Environmental Research Letters*, 12(2), 024008.
31. Garnett T, Mathewson S, Angelides P and Borthwick F (2015) Policies and actions to shift eating patterns: What works? A review of the evidence of the effectiveness of interventions aimed at shifting diets in more sustainable and healthy directions. Food Climate Research Network, University of Oxford.
32. Gasparri, N. I., Kuemmerle, T., Meyfroidt, P., Waroux, Y., & Kreft, H. (2016). The emerging soybean production frontier in Southern Africa: Conservation challenges and the role of south-south telecouplings. Conservation Letters, 9(1), 21-31.
33. Godar, J., Suavet, C., Gardner, T. A., Dawkins, E., & Meyfroidt, P. (2016). Balancing detail and scale in assessing transparency to improve the governance of agricultural commodity supply chains. Environmental Research Letters, 11(3), 035015.
34. Grassini, P., Eskridge, K. M., & Cassman, K. G. (2013). Distinguishing between yield advances and yield plateaus in historical crop production trends. *Nature communications*, *4*, 2918.
35. Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., et al. (2013). High-resolution global maps of 21st-century forest cover change. Science, 342, 850-853.
36. Hecht, S. B., Morrison, K. D., & Padoch, C. (Eds.). (2014). *The social lives of forests: past, present, and future of woodland resurgence*. University of Chicago Press.
37. Hedenus, F., Wirsenius, S., & Johansson, D. J. (2014). The importance of reduced meat and dairy consumption for meeting stringent climate change targets. Climatic change, 124(1-2), 79-91.
38. Henders, S., Persson, U. M., & Kastner, T. (2015). Trading forests: land-use change and carbon emissions embodied in production and exports of forest-risk commodities. *Environmental Research Letters*, 10(12), 125012.
39. Herrmann R. T. (2017). Large-Scale Agricultural Investments and Smallholder Welfare: A Comparison of Wage Labor and Outgrower Channels in Tanzania. World Development, 90, 294-310.
40. Hertel, T. W. (2016). Food security under climate change. *Nature Climate Change*, *6*(1), 10-13.
41. Hertel, T. W., & Baldos, U. L. C. (2015). *Global Change and the Challenges of Sustainably Feeding a Growing Planet*. Springer.
42. Hertel, T. W., Baldos, U. L. C., & van der Mensbrugghe, D. (2016). Predicting Long-Term Food Demand, Cropland Use, and Prices. Annual Review of Resource Economics, 8, 417-441.
43. Hertel, T. W., Ramankutty, N., & Baldos, U. L. C. (2014). Global market integration increases likelihood that a future African Green Revolution could increase crop land use and CO2 emissions. *Proceedings of the National Academy of Sciences*, *111*(38), 13799-13804.
44. Holt-Giménez, E., Shattuck, A., Altieri, M., Herren, H., & Gliessman, S. (2012). We already grow enough food for 10 billion people… and still can't end hunger. Journal of Sustainable Agriculture, 36(6), 595-598.
45. Ivanic, M., & Martin, W. J. (2014). Short-and long-run impacts of food price changes on poverty. World Bank Policy Research Working Paper 7011. World Bank.
46. Jadin I, Meyfroidt P, Lambin EF (2016) International trade, and land use intensification and spatial reorganization explain Costa Rica's forest transition. *Environmental Research Letters*, 11 (3), 035005
47. Jayne T. S., Chamberlin J., Traub L., Sitko N., Muyanga M., Yeboah F. K., Anseeuw W., Chapoto A., Wineman A., Knonde C., Kachule R. (2016). Africa's changing farm size distribution patterns: the rise of medium-scale farms. *Agricultural Economics*, 47(S1), 197-214.
48. Jayne, T. S., Chamberlin, J., & Headey, D. D. (2014). Land pressures, the evolution of farming systems, and development strategies in Africa: A synthesis. Food Policy, 48, 1-17.
49. Jayne, T. S., Chamberlin, J., & Muyangay, M. (2014). Emerging land issues in African agriculture: Implications for food security and poverty reduction strategies. In Falcon W. P., Naylor R. L., Frontiers in Food Policy: Perspectives on sub-Saharan Africa. Stanford University's Global Food Policy and Food Security Symposium Series. Center on Food Security and the Environment. Stanford, CA, USA, University of Stanford.
50. Kastner, T., Erb, K. H., & Haberl, H. (2014). Rapid growth in agricultural trade: effects on global area efficiency and the role of management. *Environmental Research Letters*, 9(3), 034015.
51. Kastner, T., Rivas, M. J. I., Koch, W., & Nonhebel, S. (2012). Global changes in diets and the consequences for land requirements for food. Proceedings of the National Academy of Sciences, 109(18), 6868-6872.

52. Lambin EF, Gibbs HK, Ferreira L, Grau R, Mayaux P, Meyfroidt P, Morton DC, Rudel TK, Gasparri I, Munger J (2013). Estimating the world's potentially available cropland using a bottom-up approach. Global Environmental Change, 23(5), 892-901
53. Lambin EF, Meyfroidt P (2014). Global land use competition. In Seto K, Reenberg A (eds): Rethinking Global Land Use in an Urban Era, Strüngmann Forum Reports, vol. 14. Cambridge, MA: MIT Press.
54. Lambin EF, Meyfroidt P, Rueda X, Blackman A, Börner J, Cerutti PO, Dietsch T, Jungmann L, Lamarque P, Lister J, Walker NF, Wunder S. Effectiveness and synergies of private and public actions for land use governance in tropical regions (2014). *Global Environmental Change*, 28, 129-140
55. Le Mouël C, Marajo-Petitzon E., Dumas P., Manceron S., Forslund A., Mora O. (2016). Simulation results of the Agrimonde-Terra's scenarios. Agrimonde-Terra foresight: Land use and food security in 2050 Technical report, 31 p.
56. Le Polain de Waroux, Y., Garrett, R. D., Heilmayr, R., & Lambin, E. F. (2016). Land-use policies and corporate investments in agriculture in the Gran Chaco and Chiquitano. *Proceedings of the National Academy of Sciences*, 113(15), 4021-4026.
57. Lea, D. (2008). The expansion and restructuring of intellectual property and its implications for the developing world. *Ethical Theory and Moral Practice*, 11(1), 37-60.
58. Lemaux, P. G. (2009). Genetically engineered plants and foods: a scientist's analysis of the issues (Part II). *Annual review of plant biology*, 60, 511-559.
59. Li, T. M. (2011). Centering labor in the land grab debate. *The Journal of Peasant Studies*, *38*(2), 281-298.
60. Lobell, D. B., Cassman, K. G., & Field, C. B. (2009). Crop yield gaps: their importance, magnitudes, and causes. *Annual review of environment and resources*, 34, 179-204.
61. Maertens M., Minten B., Swinnen J. (2012). Modern Food Supply Chains and Development: Evidence from Horticulture Export Sectors in Sub-Saharan Africa. Development Policy Review, 30(4), 473-497.
62. Maertens, M., & Swinnen, J. F. (2009). Trade, standards, and poverty: Evidence from Senegal. World development, 37(1), 161-178.
63. Martin, W., & Ivanic, M. (2016). Food Price Changes, Price Insulation, and Their Impacts on Global and Domestic Poverty. In Food Price Volatility and Its Implications for Food Security and Policy (pp. 101-113).
64. Meyfroidt P, Carlson KM, Fagan ME, Gutiérrez-Vélez VH, Macedo MN, Curran LM, DeFries RS, Dyer GA, Gibbs HK, Lambin EF, Morton DC, Robiglio V (2014). Multiple pathways of commodity crop expansion in tropical forest landscapes. Environmental Research Letters, 9 074012
65. Meyfroidt, P., Lambin, E. F. (2008). The causes of the reforestation in Vietnam. Land use policy, 25(2), 182-197.
66. Meyfroidt P, Vu TP, Hoang VA (2013). Trajectories of deforestation, coffee expansion and displacement of shifting cultivation in the Central highlands of Vietnam. Global Environmental Change, 23(5), 1187-1198
67. Meyfroidt, P., Schierhorn, F., Prishchepov, A. V., Müller, D., & Kuemmerle, T. (2016). Drivers, constraints and trade-offs associated with recultivating abandoned cropland in Russia, Ukraine and Kazakhstan. Global Environmental Change, 37, 1-15.
68. Morris, M. L., Binswanger-Mikhize, H. P., & Byerlee, D. (2009). Awakening Africa's sleeping giant: prospects for commercial agriculture in the Guinea Savannah Zone and beyond. World Bank Publications.
69. Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C., & Gerber, P. (2017). Livestock: On our plates or eating at our table? A new analysis of the feed/food debate. *Global Food Security*. In press, http://dx.doi.org/10.1016/j.gfs.2017.01.001
70. Mueller, N. D., Gerber, J. S., Johnston, M., Ray, D. K., Ramankutty, N., & Foley, J. A. (2012). Closing yield gaps through nutrient and water management. *Nature*, 490(7419), 254-257.
71. Naylor, R. L. (2016). Oil crops, aquaculture, and the rising role of demand: A fresh perspective on food security. Global Food Security, 11, 17-25.
72. Neven D., Odera M. M., Reardon T., Wang H. (2009). Kenyan supermarkets, emerging middle-class horticultural farmers, and employment impacts on the rural poor. World Development, 37(11), 1802-1811.
73. Nordhaus T., Shellenberger M., Blomqvist L. (2015) George Monbiot is wrong to suggest small farms are best for humans and nature. The Guardian, September 25 2015.

74. Oberlack, C., Tejada, L., Messerli, P., Rist, S., & Giger, M. (2016). Sustainable livelihoods in the global land rush? Archetypes of livelihood vulnerability and sustainability potentials. *Global Environmental Change*, *41*, 153-171.
75. Pingali, P. (2007). Westernization of Asian diets and the transformation of food systems: Implications for research and policy. *Food policy*, 32(3), 281-298.
76. Ray, D. K., Mueller, N. D., West, P. C., & Foley, J. A. (2013). Yield trends are insufficient to double global crop production by 2050. *PloS one*, 8(6), e66428.
77. Ray, D. K., Ramankutty, N., Mueller, N. D., West, P. C., & Foley, J. A. (2012). Recent patterns of crop yield growth and stagnation. *Nature communications*, 3, 1293.
78. Revell, B. J. (2015). One man's meat… 2050? ruminations on future meat demand in the context of global warming. Journal of Agricultural Economics, 66(3), 573-614.
79. Rudel, T., Meyfroidt, P. (2014). Organizing anarchy: The food security–biodiversity–climate crisis and the genesis of rural land use planning in the developing world. *Land Use Policy*, 36, 239–247
80. Rudel, T.K., Schneider, L., Uriarte, M., Turner, B.L., DeFries, R., Lawrence, D., Geoghegan, J., Hecht, S., Ickowitz, A., Lambin, E.F., Birkenholtz, T., Baptista, S., Grau, R. (2009) Agricultural intensification and changes in cultivated areas, 1970–2005. *Proc. Natl. Acad. Sci. USA*, 106, 20675–20680
81. Rueda, X., Thomas, N. E., & Lambin, E. F. (2015). Eco-certification and coffee cultivation enhance tree cover and forest connectivity in the Colombian coffee landscapes. *Regional environmental change*, *15*(1), 25-33.
82. Rueda, X., Garrett, R. D., & Lambin, E. F. (2017). Corporate investments in supply chain sustainability: Selecting instruments in the agri-food industry. Journal of Cleaner Production, 142, 2480-2492.
83. Rueda, X., & Lambin, E. F. (2014). Global Agriculture and Land Use Changes in the Twenty-First Century. In Naylor, R. L. (Ed) The evolving sphere of food security, Oxford University Press.
84. Samberg, L. H., Gerber, J. S., Ramankutty, N., Herrero, M., & West, P. C. (2016). Subnational distribution of average farm size and smallholder contributions to global food production. Environmental Research Letters, 11(12), 124010.
85. Schierhorn, F., Müller, D., Beringer, T., Prishchepov, A. V., Kuemmerle, T., & Balmann, A. (2013). Post-Soviet cropland abandonment and carbon sequestration in European Russia, Ukraine, and Belarus. *Global Biogeochemical Cycles*, 27(4), 1175-1185.
86. Searchinger, T.D., Estes, L., Thornton, P.K., Beringer, T., Notenbaert, A., Rubenstein, D., Heimlich, D., Licker, R., Herrero, M., 2015. High carbon and biodiversity costs from converting Africa’s wet Savannahs to cropland. Nat. Climate Change 5 (5), 481–486.
87. Smart T., Hanlon J. (2014). Chickens and beer: recipe for agricultural growth in Mozambique. Maputo, Open University / Ciedima.
88. Swinnen, J., & Squicciarini, P. (2012). Mixed messages on prices and food security. Science, 335(6067), 405-406.
89. Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences, 108(50), 20260-20264.
90. United Nations, Department of Economic and Social Affairs, Population Division (2015). World Population Prospects: The 2015 Revision. New York.
91. Villoria, N. B., Byerlee, D., & Stevenson, J. (2014). The Effects of Agricultural Technological Progress on Deforestation: What Do We Really Know? Applied Economic Perspectives and Policy 36(2), 211– 237
92. Vranken, L., Avermaete, T., Petalios, D., & Mathijs, E. (2014). Curbing global meat consumption: emerging evidence of a second nutrition transition. Environmental Science & Policy, 39, 95-106.
93. Wirsenius, S., Hedenus, F., & Mohlin, K. (2011). Greenhouse gas taxes on animal food products: rationale, tax scheme and climate mitigation effects. Climatic Change, 108(1), 159-184.
94. zu Ermgassen, E. K., Phalan, B., Green, R. E., & Balmford, A. (2016). Reducing the land use of EU pork production: where there’s swill, there’s a way. Food *policy*, 58, 35-48.