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Commentary

Competition for land: A sociometabolic perspective

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ABSTRACT

Possible negative effects of increased competition for land include pressures on biodiversity, rising food prices and GHG emissions. However, neoclassical economists often highlight positive aspects of competition, e.g. increased efficiency and innovation. Competition for land occurs when several agents demand the same good or service produced from a limited area. It implies that when one agent acquires scarce resources from land, less resource is available for competing agents. The resource competed for is often not land but rather its function for biomass production, which may be supplanted by other inputs that raise yields. Increased competition may stimulate efficiency but negative environmental effects are likely in the absence of appropriate regulations. Competition between affluent countries with poor people in subsistence economies likely results in adverse social and development outcomes if not mitigated through effective policies. The socioecological metabolism approach is a framework to analyze land-related limits and functions in particular with respect to production and consumption of biomass and carbon sequestration. It can generate databases that consistently link land used with biomass flows which are useful in understanding interlinkages between different products and services and thereby help to analyze systemic feedbacks in the global land system.

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1. Introduction

Motivated by surging prices of many agricultural products, competition for land has received increased attention (Coelho et al., 2012; Lambin and Meyfroidt, 2011; Haberl et al., 2014; Smith et al., 2010, 2014, in press). Concerns related to competition for land include environmental issues such as increasing pressure on forested areas and ecologically valuable, biologically diverse ecosystems. In addition, food prices, and therefore land rents, may increase as a result of drivers such as the rising food demand of the growing world population together with increased bioenergy demand and regulations to reduce losses of forest or other valuable ecosystems, which may constrain the expansion of farmland for food production (Popp et al., 2011; Wise et al., 2009). While rising prices of land or its products may benefit land owners/users, they negatively affect consumers and may reduce food security. Loss of forests or other carbon-rich ecosystems related to the area demand of additional bioenergy provision may result in increased greenhouse gas (GHG) emissions, thereby counteracting or even negating the stated aim of bioenergy policies to mitigate climate change (e.g., Creutzig et al., in press; Haberl, 2013; Searchinger et al., 2008; Smith et al., in press).

In this literature, competition for land is largely seen as detrimental, resulting in rising prices for agricultural products, reduced food security, loss of valuable ecosystems or GHG emissions (Coelho et al., 2012). Competition for land is a systemic phenomenon resulting from the interplay of the above-mentioned or other drivers (Smith et al., 2010, in press). Motivated by concerns over a “looming land scarcity” (Lambin and Meyfroidt, 2011), classifications for different types of competition for land have been proposed: production vs. production (e.g. food vs. fuel), production vs. conservation (e.g. food vs. nature conservation) or built-up or urban vs. production or conservation (Haberl et al., 2014).

Although scholars from both economics and ecology recognize potentially detrimental effects of competition, they also identify positive aspects, e.g., by exerting pressure to raise efficiency and foster innovation. Interestingly, such effects have so far not featured prominently in the discussion of competition for land, although they were not completely ignored. For example, it was argued that increased competition for land from growing bioenergy supply under the assumption that forest area is protected will stimulate technological progress in raising agricultural yields, albeit at higher monetary (Popp et al., 2012) and ecological (IAASTD, 2009; Smith et al., 2014) costs.

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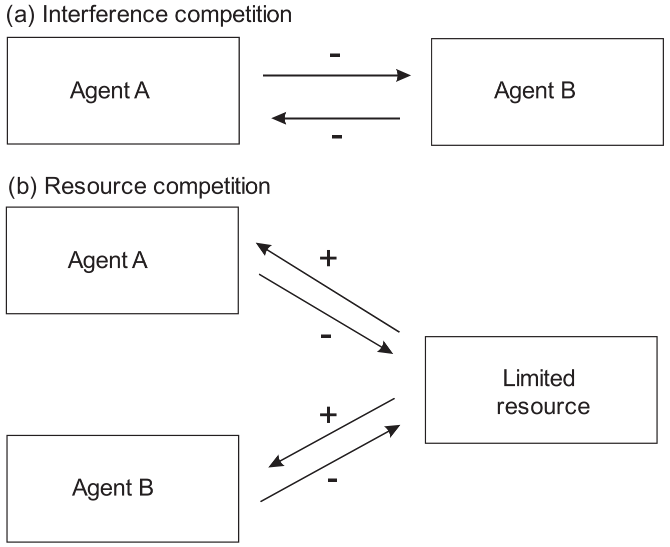

Fig. 1. Two meanings of the notion "competition" as used in the ecological literature, shown here in the simplest case with only two competing agents.
Source: own graph, after Birch, 1957; Passarge and Huisman, 2002.

This article aims to discuss the potential merits of the socioeconomic metabolism approach in analyzing competition for land. It starts by summarizing the meaning of competition in various disciplines, in particular ecology and economics, and relates it to land (Section 2). The potential contribution of a sociometabolic perspective to understanding competition for land is discussed in Section 3. Section 4 provides outlook and conclusions.

2. What is Competition for Land?

2.1. Competition in Ecology and Economics

The notion of competition is used in many scientific disciplines with widely varying meanings depending on the context. In this article, I focus on two concepts from the ecological literature, (a) interference competition and (b) resource competition (Fig. 1). In both concepts, competition includes a negative effect of one agent on another. Interference competition means that agents harm each other directly when trying to acquire a scarce resource. In resource competition, the negative effect results from reduced availability of the resource for the inferior competitor.

In ecology, "agents" may be individual organisms of the same species ("intraspecific competition") or different species ("interspecific competition"). Intraspecific competition is a density-dependent process that limits population growth, whereas interspecific competition is one of the main biotic interactions structuring biotic communities and playing an important role in evolutionary processes (Cain et al., 2008). Some detrimental direct interactions between organisms such as predation or parasitism are usually[1] excluded from the definition of competition (Birch, 1957), mainly because predator–prey and parasite–host relations mostly result in the coexistence of both species. In contrast, an important aim of ecologists is to understand the role of competition in structuring biological communities through what is called the "competitive exclusion principle," i.e. the assumption that among two species using the same resource in the same way, one species will outcompete the other – in other words, two species using the same resource in the same way cannot coexist (Gause, 1934; Hardin, 1960).[2] An important distinction is that between resources and factors: While factors (e.g. temperature) may affect organisms, they are not depleted — in contrast to resources such as water, nutrients, food, sunlight or space: if a resource is used or occupied by one organism, the availability of that resource for another organism is reduced by that amount.[3] While detrimental effects of competition on inferior competitors are recognized, the ecological literature also highlights some of its positive aspects, e.g. as part of evolutionary processes or in the regulation of populations in ecosystems (Cain et al., 2008).

In neoclassical economics, competition is cherished as the force guaranteeing that interactions of profit-maximizing, self-interested individuals on markets result in both productive and allocative efficiency. Competition is seen as Adam Smith's famous invisible hand in action, securing optimal use of scarce resources in meeting society's unlimited wants (Rohlf, 2008). Neoclassical economists usually distinguish situations of competition in "perfect markets" (numerous buyers and sellers with complete information on supply and demand prices trade homogenous goods) from "imperfect markets" where these assumptions are to some extent violated. The complementary notion of Schumpeterian "entrepreneurial competition" is focused on the role of "creative destruction" and innovation: successful introduction of new products by entrepreneurs allows them to escape competition for some period in which they can enjoy the benefits of being "temporary monopolists." This phase is, however, soon followed by imitation by other producers resulting in renewed competition that reduces monopoly rents. Entrepreneurial competition hence allows for (at least temporary) coexistence of cooperation and coordination (which are both involved in innovation) with competition (Breton, 1996).[4]

Because competition is seen as a key element of technological progress and economic efficiency, it is widely accepted that it should be promoted by the state through appropriate policies, e.g. by antitrust laws preventing monopolies hence enabling competition and by regulations ensuring market fairness and avoiding collusion (Molitor, 1992). One might say that, while they regard resource competition as benign, neoclassical economists tend to call for rules to exclude most forms of "interference competition" according to Fig. 1. Only for few markets would many neoclassical economists agree that they should be excluded from competition, e.g. in the case of products or services where economies of scale are large enough to justify natural monopolies (Sharkey, 1983), e.g. electricity grids, or for public goods that cannot be procured profitably by private companies (Rohlf, 2008).

However, not all economists agree that competition is overwhelmingly benign. Even neoclassical economists usually accept that markets fail to result in socially optimal outcomes when external costs are not properly reflected in prices (Rohlf, 2008). Ecological economists have suggested that international competition may result in a "race to the bottom" of social and environmental standards leading to inequality,

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[1] Sometimes the notion of competition is used so broadly that it becomes more or less synonymous with "selection"; i.e. any process contributing to the "struggle for existence" would fall within that concept – a use of the notion that is, however, mostly seen to be too inclusive to be useful (Birch, 1957).

[2] This notion has been extended to the hypothesis that n species can co-exist on n resources in well-mixed habitats (Levin, 1970). Species may coexist, however, if they use the same resource differently as a result of "resource partitioning" (Cain et al., 2008). Later work has suggested that the frequency and severity of disturbances may alleviate such restrictions and allow more species to coexist, i.e. the "intermediate disturbance" hypothesis (Connell, 1978). Current work suggests that species interaction may produce unstable or chaotic dynamics and equilibrium may be the exception rather than the rule in ecosystems; hence competitive exclusion in equilibrium systems may be a lot less ubiquitous than previously thought (Passarge and Huisman, 2002; Sommer and Worm, 2002).

[3] A substance may be a resource or a factor, depending on the circumstances. For example, although animals use oxygen it usually does not become scarce (and hence is not a limited resource) under free air conditions — but in the soil it is a limited resource for which competition may be intensive (Cain et al., 2008).

[4] The economic competition framework has been extended to the political sphere in a concept claiming that governments compete in several ways: between its own components, among each other, as well as with private actors (companies) in supplying goods and services (Breton, 1996).

poverty, and environmental destruction (Daly, 1993). Structural inequalities between rich countries of the Global North and poor countries of the Global South are thought to result in environmental cost shifting (Muradian and Martinez-Alier, 2001) and "ecologically unequal exchange" (Hornborg, 1998). Societies which depend to a substantial degree on land for their subsistence – and hence only to some extent rely on markets organized by money flows – often use "languages of valuation" that are incompatible with the money-based cost–benefit analyses underlying competition in market economies. In many cases, they lack effective institutions and governance to protect their resource access. These societies usually fare badly when competing over the resources that sustain their livelihoods, e.g. productive land, clean water or genotypes of animals and plants they use, with companies supplying resources to consumers in urban centers in industrialized countries (Martinez-Alier, 2002). There are many documented cases where such resource struggles have escalated into violent conflicts (Adano et al., 2012; Alston et al., 2000; Anguelovski and Martínez Alier, 2014), i.e. interference competition.

2.2. Land as a Resource

Competition for land is a form of resource competition, with land being the finite and, in the short run, non-renewable resource for which different actors (e.g., firms) compete. The scheme in Fig. 1 can be useful to inspire questions such as the following:

1. What functions of land are competed for? In many cases, other resources can substitute land as an input, e.g. when fossil fuels replace biomass as an energy source. Indeed, attempts to revert that trend by substituting biomass for fossil fuels is one of the main drivers of rising competition for land (Smith et al., 2010). Different functions of land are mutually exclusive, while others can be combined, e.g. in multifunctional landscapes (e.g. de Groot, 2006; Coelho et al., 2012).
2. In what sense is land limited? While the planet's land surface is finite, its output in terms of agricultural or forestry products can be increased through land-use intensification; however, in this case other resources are required, such as fertilizer or labor (Boserup, 1965; Erb et al., 2013; Turner and Doolittle, 1978).
3. Who are the actors that compete? What are the functions of land they need or desire? Often the same actor requires more than one competing function (e.g. consumers want habitation, food, fuel and biodiversity).
4. What are the mechanisms of competition and in which institutional setting is it played out? Examples are markets (for land and products from land), regulation, social or political conflicts discussed in political ecology (Martinez-Alier, 2002; Martinez-Alier et al., 2010). The "land grab" discussion (Anguelovski and Martínez Alier, 2014; Friis and Reenberg, 2010; Messerli et al., 2013) is a good example for the importance of asking which actors compete for land in what social setting. It shows that institutional and social contexts in which competition for land and other resources is played out are important, including factors such as development context, property rights, land tenure or bargaining power, which are influencing its outcomes (Bustamante et al., 2014; Creutzig et al., 2013).

To tackle these questions it is useful to consider the socioeconomic functions of land (Verburg et al., 2009); e.g. based on the ecosystem service framework. Apart from its obvious function to provide space for buildings and infrastructures, as well as area required for mining and waste deposits (Dunlap and Catton, 2002), land is valued for the provisioning, regulating, and cultural ecosystem services it provides (Braat and de Groot, 2012; Millennium Ecosystem Assessment, 2005). Using land for buildings and infrastructures excludes or strongly reduces other services, except for cases such as greenhouse horticulture or vertical gardening. Cities and rural settlements, representing a mosaic of buildings and vegetated spaces, may nevertheless host biologically diverse communities delivering a variety of ecosystem services (Haase et al., 2014).

Apart from hunting and gathering, the delivery of provisioning services by land largely depends on its societal colonization, i.e. purposive alteration through agriculture (cropping, livestock rearing) and forestry (Fischer-Kowalski and Haberl, 1997). The quantities of products delivered – food, feed, fiber, bioenergy – depend on the suitability and management of the land, in particular on land-use intensity (Boserup, 1965; Erb et al., 2013; Turner and Doolittle, 1978; Section 3). However, agriculture and forestry often exclude or reduce the delivery of ecosystem services other than biomass production, e.g. biodiversity or carbon storage. Activities to increase biomass production (land-use expansion and intensification) often reduce other ecosystem services such as self-regulating capacities or carbon storage and biodiversity (Seppelt et al., 2013). The land-sharing vs. land-sparing framework can help in analyzing biodiversity outcomes resulting from trade-offs between land "spared" for conservation through intensification of agriculture vs. the use of larger areas in a manner that reduces pressures on biodiversity at the expense of reduced productivity per unit area (Grau et al., 2013; Phalan et al., 2011). Trade-offs between biodiversity and agricultural production depend on the spatial configurations of landscapes (Sabatier et al., 2013) and may be mitigated through establishment of appropriate "land system architectures" (Turner et al., 2013). There are also trade-offs between biomass production and carbon sequestration: high output of biomass requires conversion of forests (high carbon stocks, low production) into agro-ecosystems (cropland and pastures with lower carbon stocks). Although some carbon can be sequestered on cropland e.g. through reduced tillage or use of organic fertilizers, cropland still stores much less carbon per unit area than forests (Smith et al., in press).

Land is not substitutable by other resources when needed as space for buildings or infrastructures, and very difficult to replace altogether as far as food production is concerned, but many other functions of land for resource supply can be, and have been, supplanted. For example, exploitation of the "subterranean forest" in coal deposits triggered an energy transition from biomass to fossil fuels, the agrarian–industrial transition, and has greatly reduced the role of land for securing society's energy supply (Sieferle, 2001). Land area required for mining of mineral resources, including fossil energy, may be substantial on local and regional scales and result in competition with other land uses on local or region scales (Haberl et al., 2014). But the area required per unit of energy supplied is orders of magnitude smaller than if biomass is used for energy production (Coelho et al., 2012). The switch from biomass to mineral resources (e.g. fossil fuels) almost eliminated land-related limits to resource supply during the agrarian–industrial transition: it opened up the possibility to replace biomass with mineral resources requiring much less land, and it allowed to hugely increase the productivity of land for food and other resources. Both processes have unleashed henceforth unknown surges of material and energy supply (Fischer-Kowalski and Haberl, 2007). To what extent current early warning signals of land scarcity (Lambin and Meyfroidt, 2011) actually signify the approaching of planetary (Rockström et al., 2009) or regional (Dearing et al., 2014) boundaries is contested due to the option to switch to other resources or to increase the productivity of land (Section 3).

3. A Sociometabolic Perspective on Competition for Land

The socioeconomic use of biophysical resources such as raw materials or energy can be analyzed within the concept of socioeconomic metabolism. This approach has generated accounts of societal material and energy use as well as indicators of socioecological metabolism such as the "human appropriation of net primary production" (abbreviated as HANPP). This section discusses how these concepts can help in analyzing land-use competition.

3.1. Socioeconomic and Socioecological Metabolism

In the last decades the socioeconomic metabolism approach has gained importance as a concept to analyze society–nature interaction (Ayres and Simonis, 1994; Fischer-Kowalski, 1998; Martinez-Alier, 1987). The analysis of material and energy flows involved in production and consumption has provided an interdisciplinary framework bridging social and natural sciences with humanities in investigating resource efficiency, socioecological transitions, North–South relations and other aspects of sustainability (Fischer-Kowalski and Haberl, 1997, 2007; Muradian and Martinez-Alier, 2001).

The sociometabolic approach is useful in analyzing land systems, in particular when extended to a "socioecological metabolism" approach in which biophysical flows (materials, energy, or carbon) of integrated socioecological systems are analyzed. In addition to the socioeconomic stocks and flows included in socioeconomic metabolism, this latter approach also includes stocks and flows of materials and energy in ecosystems (Erb, 2012; Haberl et al., 2013a). The "human appropriation of net primary production" (HANPP) encompasses socioeconomic flows (e.g. biomass harvest) and changes in ecological energy flows such as alterations of net primary production (NPP) resulting from land use (Vitousek et al., 1986; Wright, 1990; Haberl, 1997). NPP is the biomass produced by green plants through photosynthesis. HANPP is the combined effect of land-use related productivity changes and harvest on biomass availability in the ecosystem (Haberl, 1997).

3.2. A Sociometabolic Approach for Analyzing Land Scarcity

Global land is limited. Excluding Antarctica and Greenland, which are almost entirely covered by ice shields and hence unproductive, the area of the earth's lands is ~130 million km^2 or Mkm^2 (discussions below refer to that land area). One quarter of that land has been classified as largely natural (Ellis et al., 2013; Erb et al., 2007), three quarters are used more or less intensively for settlements and infrastructures, croplands, grazing and forestry. Most of the "natural" area is fairly unproductive, being cold, dry, or both; only 5–7% of global land is highly productive and unused, which are the remnants of the world's pristine forests (Erb et al., 2007). Apart from the possibility to further encroach pristine forests, all additional demands for land-related resources must be met by changing or intensifying land use within the three quarters of the global land that is already used, which involves competition between land uses: either existing land-use practices change within the same land-use class (e.g. from traditional to high-input cropping) or land use is altered, e.g. from grazing to cropping.

Land classified as "abandoned", "degraded" or "residual" but deemed suitable for human use (FAO and IIASA, 2000) is seldom entirely unused: it is often used for cropping and grazing or as fallow land in rotational cropping systems by agro-pastoralists and subsistence-oriented farmers who are not accounted for in official statistics, or it may be used for extensive grazing, hunting, forestry and the collection of non-timber forestry products (Coelho et al., 2012; Erb et al., 2007; Young, 1999). In addition, abandoned land often hosts regenerating vegetation that supports biodiversity and carbon stocks in regenerating vegetation and soils (Kuemmerle et al., 2011; Schierhorn et al., 2013).

The area of land may be less important than its biophysical capacity to supply biomass for food, feed, fiber and energy or to sequester carbon. Biomass production potentials can be measured as dry matter biomass, its carbon content or its energy equivalent.[5] NPP is the total biomass flow available in ecosystems per year for heterotrophic food webs (animals, fungi, microorganisms) plus (potentially) the addition of carbon to the carbon stocks in biota and soils (Haberl, 2013). The fraction of land used for cropping (Rockström et al., 2009) may be less useful as an indicator of planetary boundaries than the amount of yearly available and accessible NPP, respectively the level of human use of that resource as indicated by HANPP (Running, 2012; Erb et al., 2012a; Haberl et al., 2013b).

3.3. Global Socioecological Biomass Flows and Competition for Land

To the extent that competition for land results from competition for biomass, it is useful to analyze the magnitude of the total available resource, i.e. NPP, and its human use, i.e. HANPP. Data derived from remote sensing using the MODIS (Moderate Resolution Imaging Spectroradiometer) NPP algorithm suggest that global terrestrial NPP was constant from 1982 to 2009 at ~108 billion tons of dry-matter biomass (Gt/yr), with <2% year-to-year variation (Running, 2012), despite considerable increases in land-use intensity (Krausmann et al., 2013). By contrast, results of a dynamic global vegetation model indicate that terrestrial NPP increased by 7% from 1980 to 2005 (Krausmann et al., 2013) due to changes in land cover, land use and climate, including CO$_2$ fertilization (Houghton, 2013).

Globally, the NPP of the currently prevailing vegetation (NPP$_{act}$) is estimated at 108–118 Gt/yr (Haberl et al., 2007; Running, 2012), ~10% lower than the NPP of the potential natural vegetation assumed to exist in the absence of land use (NPP$_{pot}$). This results from human-induced land degradation, the use of land for buildings and from the fact that NPP$_{act}$ of farmland is lower than its NPP$_{pot}$ in the global average (Table 1). Recent HANPP data suggest that land use raises NPP$_{act}$ over NPP$_{pot}$ on local and regional scales, e.g. in irrigated drylands and some intensively used humid regions in Europe (Haberl et al., 2007). But the challenges as well as the monetary (Popp et al., 2012) and ecological (IAASTD, 2009; Smith et al., 2014) costs of raising NPP$_{act}$ over NPP$_{pot}$ in larger regions should not be underestimated. Raising NPP requires inputs often derived directly or indirectly from non-renewable mineral and fossil-energy resources, e.g. fuels, water, or fertilizer. While increasingly using these resources risks transgressing planetary boundaries related to climate change or biogeochemical cycles (Erb et al., 2012a; Rockström et al., 2009), it is a powerful source of gains in land-use efficiency which have greatly reduced land demand for agriculture in the past (Burney et al., 2010).

The amount of biomass withdrawn from ecosystems each year by humans (~20 Gt/yr) exceeds the amount of biomass used for feed, fiber, food or bioenergy supply (~12 Gt/yr): biomass is lost during harvest, e.g. belowground parts of annual crop plants or plant parts destroyed during harvest but not recovered, residues left in the field, and biomass burned in human-induced vegetation fires.

Table 1 gives an overview of humanity's current use of the biomass production potential of land.[6] Larger harvests on croplands are possible if NPP increases or if the ratio of commercial harvest to NPP (i.e. the harvest index) increases. Both effects have contributed to the past yield growth (Krausmann et al., 2013). Although competition on agricultural markets may have helped to achieve these increases in efficiency, public sector activities such as state-funded agricultural research have also played a major role. Until 2050, cropland area is forecast to rise by ~9% at the expense of forests as well as the "grazing and other land" category, but most additional production is expected from increased yields (FAO, 2006), especially where yield gaps are high (Mueller et al., 2012). Raising land productivity may consume substantial amounts of non-renewable resources and incur substantial ecological costs (IAASTD, 2009; Smith et al., 2014) if not based on sustainable technologies and

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[5] In this article, biomass is referred to as dry-matter (zero water content) biomass. For practical purposes one may assume that 1 kg of dry-matter biomass contains 0.5 kg carbon and has a gross calorific value of 18.5 MJ/kg (Haberl, 2013). Numbers taken from other work that had to be converted into the dry-matter units were converted using these factors.

[6] NPP$_{pot}$ and NPP$_{act}$ were estimated using a vegetation model suggesting higher NPP levels than MODIS but while this would affect the level of both NPP$_{pot}$ and NPP$_{act}$, it is unlikely to substantially affect the relation between NPP$_{pot}$ and NPP$_{act}$ (Krausmann et al., 2013).

Table 1
Global HANPP in the year 2000 and its implications for potential biomass availability and competition for biomass.
Data sources: Erb et al., 2007; Haberl et al., 2007.

	Area	NPP_{pot}	NPP_{act}	NPP_{eco}[a]	HANPP[a]	Comments (see text for detail)
	[Mkm^2]	[Gt/yr]				
Settlements	1.4	1.6	0.6	0.4	1.2	Global area expansion expected
Cropland	15.2	18.6	12.1	3.1	15.5	Increase of harvest requires raising NPP; some area expansion expected
Grazing and other land[b]	46.9	46.0	40.9	37.1	8.9	Some increase in harvest possible; cropland expansion may reduce area
Forestry	35.0	50.3	50.3	47.0	3.3	Some increases in harvest possible; cropland expansion may reduce area
Unused	32.0	14.5	14.5	14.5	–	High ecological costs of increasing harvest
Total	130.4	131.0	118.4	102.1	28.9	

NPP_{pot} — NPP of potential natural vegetation; NPP_{act} — NPP of currently prevailing vegetation; NPP_{eco} — NPP remaining in ecosystems after harvest.

[a] Excluding human-induced fires which reduce NPP_{eco} and increase HANPP by 3.5–3.8 Gt/yr but cannot be assigned to land-use classes (Lauk and Erb, 2009).

[b] See text for explanation.

collaborative activities such as technology transfer from rich to poor regions (Tilman et al., 2011).

The "grazing and other land" category displayed in Table 1 encompasses all land not included in the other land categories. This dataset was generated assuming that all lands not explicitly unused or used for settlements, cropland or forestry may be grazed, albeit sometimes at very low intensity (Erb et al., 2007). This category contains "degraded" or "abandoned" land that is often deemed available for bioenergy crops (Chum et al., 2012; Coelho et al., 2012; Nijsen et al., 2012). Most land used for subsistence-oriented agriculture and shifting cultivation is also expected to be included in that category (Erb et al., 2007). Increasing biomass supply for feed and as bioenergy feedstock from that land is possible (Haberl et al., 2013b; Smith et al., 2012). Calculations with a biomass balance model (Haberl et al., 2011; Erb et al., 2012b) that explicitly considers the competition between grazing and energy crops based on NPP and biomass use data suggest that 2–6 Gt/yr of biomass for bioenergy might become available from that land until 2050 if the land within the "grazing and other land" category can be intensified, on top of the additional biomass required for livestock grazing. Ecological costs as well as the social, political or economic challenges of expanding biomass supply from that area may be substantial (Haberl et al., 2013b). For example, excluding protected and biologically diverse areas as well as politically unstable countries reduces biomass supply potentials by ~45% (Erb et al., 2012b); potential effects on subsistence-based livelihoods are largely unknown.

The largest biomass resource remaining in ecosystems exists in forests where NPP_{eco} is almost 50 Gt/yr, but the fraction of the NPP that can be harvested in forests without conversion to herbaceous vegetation is at best ~30% (Schulze et al., 2012). Increasing biomass harvest beyond that point entails replacement of forests with grasslands or croplands and results in massive releases of carbon stored in biota and soils (Smith et al., in press). There is an intensive ongoing, and at present not conclusive, scientific debate to what extent biomass supply from forests can be increased without impairing ecosystem health and reducing carbon sinks in forests (Creutzig et al., in press; Haberl, 2013; Holtsmark, 2012; Schulze et al., 2012).

Future competition for biomass, as well as between biomass supply and carbon sequestration, depends on diets (Stehfest et al., 2009) and

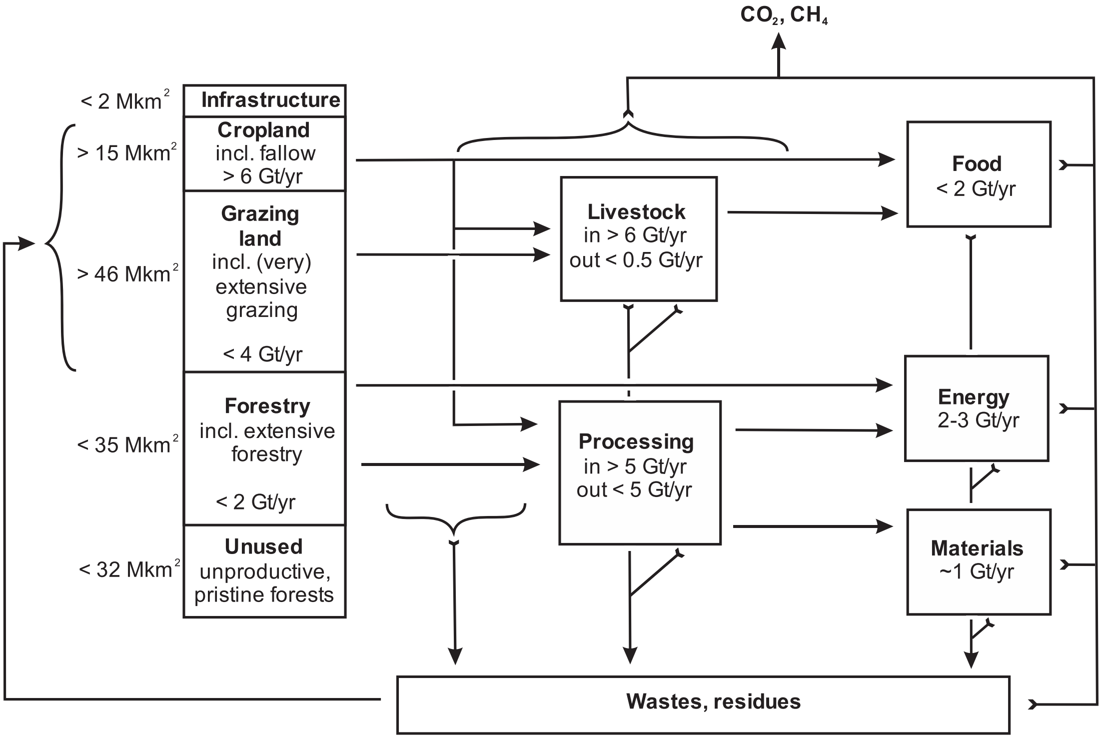

Fig. 2. Global land use [1 Mkm^2 = 10^6 km^2] and socioeconomic biomass flows [Gt/yr, 1 Gt = 10^9 tons]; biomass flows are given as dry matter biomass (approximately 0.5 kg carbon per 1 kg biomass; approximately 18.5 MJ/kg biomass).
Data sources: area (Erb et al., 2007); biomass flows (Krausmann et al., 2008; Smith et al., 2013). Own graph, strongly modified after Smith et al. (2013).

food supply chains. More than half of the entire biomass used by humans globally is fed to livestock (Fig. 2). Reducing the fraction of animal products in diets as well as losses in food supply chains can alleviate the intensity of future land-use competition (Erb et al., 2012b; Smith et al., in press). However, ruminants are capable of using lands not usable for cropland due to their ability to digest plant materials rich in fiber and low in protein and starch, which also contributes to their low feed conversion efficiency and gives them a special role in maintaining food security in many socioecological settings (Krausmann et al., 2008). Nevertheless, adopting diets with lower levels of animal products, e.g. those recommended by the Harvard medical school (Stehfest et al., 2009), would strongly reduce global competition for farmland (Smith et al., 2013).

Important synergies that could reduce competition for land might be realized through a “cascade utilization” of biomass (Haberl and Geissler, 2000; WBGU, 2009), i.e. a strategy to optimize biomass flows (Fig. 2) through increased re-use, recycling and energetic use of wastes and residues. A caveat is that reduced backflows of residues to soils result in degradation and carbon losses (Blanco-Canqui and Lal, 2009); unsustainably high levels of residue use should hence be avoided.

4. Outlook and Conclusions

Projected increases in global demands for land-based products are immense: until 2050, the world population may grow to 9–10 billion and become considerably more affluent; demand for agricultural products could rise by 70–100% (FAO, 2006; Tilman et al., 2011). Large amounts of biomass are additionally required in scenarios projecting 3–6 fold increases of global bioenergy supply over its present value of ~50 EJ/yr until 2050 (Chum et al., 2012; Smith et al., in press). Land is also expected to play a major role for mitigating climate change through carbon sequestration (Smith et al., in press); area demand for nature conservation may also rise (Haberl et al., 2014). Competition for land is therefore expected to intensify, in particular under ambitious bioenergy targets and continuation of current dietary trajectories. Foregoing possible future increases in yields, e.g. to reduce detrimental effects of agricultural intensification, might intensify competition for land area if not coupled with lower demand growth. Competition for land (and GHG emissions) can be reduced by adopting diets low in animal products and reducing food losses (Smith et al., 2013; Stehfest et al., 2009). Substantial contributions towards increased efficiency of biomass use could be achieved through “cascade utilization”, considering limits to residue use related to soil conservation. Difficulties of implementing demand-side strategies may be considerable (Smith et al., in press).

A sociometabolic perspective helps in generating land-use data that can be unambiguously and comprehensively related with NPP and biomass flows. This is useful in analyzing systemic feedbacks between different land uses and between potentially competing uses of biomass because it provides a rigorous analytical framework to reduce double counting and inconsistencies. Concepts of competition from ecology and economics can provide guidance in future research by structuring research questions, e.g. what functions of land are being competed for, to what extent they are mutually exclusive or might be reconciled, who the competing actors are and through what socioeconomic mechanisms and in what institutional framework competition is played out. Although resource competition may stimulate innovation and efficiency, socioeconomic and political contexts in which inequality between actors is strong (e.g. market vs. subsistence economies) or production competes with conservation of ecosystems, biodiversity or carbon stocks, considerable risks exist that competition increases inequalities and results in detrimental environmental outcomes. Potentially negative socioeconomic aspects of land-use competition deserve more research. Where they emerge, they need to be addressed through appropriate social, economic and environmental policies.

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