Meghan O'Brien, Helmut Schütz, Stefan Bringezu

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Monitoring tools, gaps and needs

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Wuppertal Institut

*Meghan O'Brien a,**
Helmut Schütz a
Stefan Bringezu a

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a Wuppertal Institute, Germany

* Corresponding author:
Meghan O'Brien
Wuppertal Institute for Climate, Environment and Energy
Döppersberg 19
42103 Wuppertal
Germany

E-mail: meghan.obrien@wupperinst.org
Phone: +49 202 2492-139
Fax: +49 202 2492-108

Wuppertal Institut

The land footprint of the EU bioeconomy: monitoring tools, gaps and needs

Abstract

The bioeconomy is gaining growing attention as a perceived win-win strategy for environment and economy in the EU. However, the EU already has a disproportionately high global cropland footprint compared to the world average, and uses more cropland than domestically available to supply its demand for agricultural products. There is a risk that uncontrolled growth of the bioeconomy will increase land use pressures abroad. For that reason, a monitoring system is needed to account for the global land use of European consumption. The aim of this paper is to take a closer look at the tools needed to monitor global cropland footprints, as well as the targets needed to benchmark development. This paper reviews recent developments in land footprint accounting approaches and applies the method of global land use accounting to calculate the global cropland footprint of the EU-27 for the years between 2000 and 2011. It finds a slight decrease in per capita cropland footprints over the past decade (of around 1% annually, reaching 0.29 ha/cap in 2011) and advocates promoting a further decrease in per capita cropland requirements (of around 2% annually) to reach global land use targets for keeping consumption within the safe operating space of planetary boundaries by 2030. It argues that strategic land reduction targets may still go hand in hand with the growth of a smart, innovative and sustainable bioeconomy by reinforcing the need for policies that support greater efficiency across the life-cycle and reduce wasteful and excessive consumption practices. Recommendations for further improving land footprint accounting are given.

Highlights

- Research to account for land footprints has increased recently
- Between 2000 and 2011, cropland area within the EU-27 decreased (by 6.6%)
- Cropland requirements associated with imports and exports increased (by 2.9% & 10%)
- The EU required 20 to 27% more cropland than domestically available to meet demand
- Results are generally in the same order of magnitude as other studies

Keywords

Land footprints, land use targets, bioeconomy, global land use accounting, safe operating space, consumption

1 Introduction

The bioeconomy[1] is gaining growing attention as a win-win strategy for environment and economy in the EU. In 2012 the European Commission published a 'Bioeconomy Strategy' (EC 2012) arguing that the bioeconomy has the potential to "maintain and create economic growth and jobs in rural, coastal and industrial areas, reduce fossil fuel dependence and improve the economic and environmental sustainability of primary production[2] and processing" (EC 2012, p. 2). Funding for research, especially into new industrial applications and the creation of lead markets for bio-based products, has increased substantially, in particular under the 'Industrial Leadership' pillar of the EU's Framework Programme for Research and Innovation (Horizon 2020).

At the same time the EU already has a high cropland footprint. A paper published in 2012 in this journal (Bringezu et al. 2012) found that to meet its annual demand for cropland-based food, fodder, fibre and fuels the EU is a "net importer" of cropland. In comparison to the amount of global cropland available on a per capita basis, the EU used around one-third more than the global average in 2007. This raises questions about the sustainability of pursuing a bioeconomy strategy, if it further raises the EU's global land demand.

The need to improve metrics for sustainability is underpinned by three factors:

- global trends which show high probability of increasing land competition in the future -- in particular between cropland, forests, pastures, energy crop and fast-growing tree plantations and built-up land -- in light of a growing world population and a rising middle class;
- current confusion regarding biofuel targets and difficulties to account for the climate impacts of indirect land use change – since 2012 four different proposals to regulate the amount of first-generation biofuels used to meet renewable energy targets have been made by governing bodies of the EU[3];
- visions of a sustainable economy, which increasingly promote the idea of global equity and, as such, European consumption levels which are within the planetary boundaries of a "safe and just operating space" (Raworth 2012) – for example, the European Commission envisions an economy in 2050 that is competitive, inclusive and respects resource constraints and planetary boundaries (EC 2011).

The question is, are current bioeconomy research and innovation activities aligned with attaining such visions? To answer this question, metrics for monitoring and targets for orientation are needed. The aim of this paper is to take a closer look at what kinds of tools are available and needed to monitor the global land use of European consumption. Specifically, it will present detailed information on the method of "global land use

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[1] The bioeconomy encompasses the production and consumption of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy (based on EC 2012).

[2] Primary production refers to agriculture, forestry, fisheries and aquaculture

[3] On 17 October 2012 the European Commission proposed to "cap" the amount of overall transport fuel demand that could be met by first-generation biofuels at 5% (EC 2012b). On the 11 of September 2013 the European Parliament voted to cap first-generation biofuels at 6%. On 13 June 2014 the Energy Council of the European Union reached a political agreement on the draft Directive on Indirect Land Use Change proposing a 7% first-generation cap. On 22 January 2014 the Commission published a Communication on a policy framework for climate and energy in the periods from 2020 to 2030, writing that it „does not think it appropriate to establish new targets for renewable energy or the greenhouse gas intensity of fuels used in the transport sector or any other sub-sector after 2020" (EC 2014, p. 6).

accounting" (GLUA) to calculate land footprints and highlight methodological challenges in light of bioeconomy developments and policy needs.

This paper begins with an overview of footprint accounting methods and a review of actual activities to calculate land footprints. It then describes the GLUA approach, presents key results for the EU and discusses the policy relevance of GLUA considering the state of European policies regarding bioeconomy, land and resource targets. Considerations of different footprint accounting methods, in the context of research and policy needs, are made and recommendations for further development and international harmonization of the land footprint approach are given. This paper argues that there is a risk of transferring the land use challenges currently surrounding biofuel policies to bioeconomy policies if land as a resource is not accounted for in official statistics, and that footprint accounting could fill this gap.

2 Background: "footprint" accounting

The four footprints – carbon, water, materials and land – are increasingly being discussed in the context of European policies and sustainable development goals (UNEP 2014a, EREP 2014, Tukker et al. 2014). They describe a consumption-oriented approach for monitoring environmental pressures, based on the premise that higher levels of consumption are related to higher levels of environmental degradation. Footprint is a term which was originally introduced by Wackernagle and Rees (1996) for the so-called "ecological footprint". It lumps together real and theoretical land use and is dominated by the effect of greenhouse gas emissions. In contrast, the four footprints are increasingly used to indicate the real environmental pressures and global implications of national resource consumption levels, and the four footprint categories relate closely to the European Commission's proposed "dashboard approach" for measuring resource use (EC 2011). Indicators related to the four categories differ widely in terms of conceptual and methodological maturity. Carbon and material footprint accounting is relatively advanced (Giljum et al. 2013a) and water footprints have gained some attention in both the research and public policy arenas related to globalization (e.g. Hoekstra 2003, Fraiture et al. 2004, Chapagain and Hoekstra 2004, UNEP 2012). Work on land footprints has increased only recently.

Land footprints have been defined as "the land used to produce the goods and services devoted to satisfy the domestic final demand of a country regardless of the country where this land was actually used" (Arto et al. 2012). It is seen as a powerful tool to compare the dependency of countries or world regions on foreign land, which is "embodied" in imports (Giljum et al. 2013b). Land footprints have also been assessed as "virtual" land flows (e.g. Würtenberger et al. 2006, van der Spleen 2009, von Witzke and Noleppa 2010, Köellner and van der Sleen 2011, Fader et al. 2011, Qiang et al. 2013, Meier et al. 2014). Von Witzke and Noleppa (2010) define virtual land as the amount of land that is required to produce one unit of a given agricultural good. It is important to make a distinction here between the 'ecological footprint' (Wackernagel and Rees 1996), which calculates a theoretical land area – used to indicate the amount of land and sea area that would be needed to supply resource consumption and absorb emissions -- and land footprints, or virtual land, which aim to provide a measure of actual land use.

Land footprints can be used to compare the global land use of different national economies, and thereby highlight inequalities in the scale of land use between regions. When time series reveal a growing imbalance between area of production and area of consumption, this may indicate problem shifting between regions (e.g. outsourcing). As regards environmental impacts, global land use *change* towards more intensive types of land use may serve as a generic environmental pressure indicator. This is because the expansion of more intensively used areas generally leads to a loss of local biodiversity, topsoil degradation and enhanced pollution. While land footprints cannot be used to quantify the final impacts on biodiversity or ecosystems, it is useful to indicate that there is a pressure towards this end, and to link this pressure to the driving forces in the production and consumption systems of single countries (Bringezu et al. 2009a).

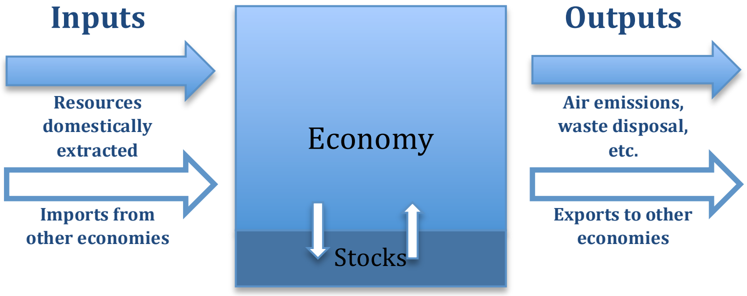
The scope, aim and focus of studies calculating land footprints differ widely. Many studies aim to capture the land footprint associated with specific products or product groups, like meat (e.g. Giljum et al. 2013b, Burke et al. 2008) or bioenergy (e.g. Ecofys 2013, de Schutter and Giljum 2014). A number of studies look at the dietary patterns associated with the land footprints of specific countries or groups of countries (e.g. Gerbens-Leenes and Nonhebel 2005, Fader et al. 2013, Kastner et al. 2013, Meier et al. 2014). Other studies have focused on specific countries, like China (Qiang et al. 2013 for both primary crops and processed products), Austria (Kastner et al. 2011 using the example of soy), Turkey (Bruckner et al. 2012), Switzerland (Würtenberger et al. 2006 using the example of wheat, Zah et al. 2010), Germany (Bringezu et al. 2009b) and the EU (Van der Sleen 2009, Von Witzke and Noleppa 2011, Lugschitz et al. 2011, Bringezu et al. 2012, Arto et al. 2012, Weinzettel et al. 2013, Yu et al. 2013, Bruckner et al. 2014). The types of land examined also differ, depending partially on the approach applied. Most of the studies account for cropland, whereas work to account for pastures and forests is less advanced (see below).

This chapter reviews the two basic approaches for accounting for land footprints: based on using an economy-wide material flow analysis approach (Section 2.1) and based on using an input-output approach (Section 2.2). In the big picture, considerations of national footprints need to be put into perspective of global trends and resource limits in order to address the question of whether national consumption levels are sustainable. In other words, whether countries are overexploiting available resources. To this end, section 2.3 presents a short review of the state of research on potential land use targets.

2.1 Accounting for consumption using economy-wide material flow analysis

The physical consumption of national economies is accounted for using economy-wide material flow analysis (ew-MFA). This is a method that looks at the flows of material resources at the macro level (Figure 1). It is based on the concept of the industrial metabolism (Ayres and Simonis 1994), which portrays the interrelationships between the socio-economic system and the biogeosphere. For example, it shows how the socio-economic system uses inputs from the environment (natural resources) for production and consumption and expels them back into the environment (as emissions or as waste).

Figure 1: Scope of material flow analysis



Source: Based on Eurostat 2009

Despite being a relatively young field of research, ew-MFA has expanded rapidly. Eurostat, based on its guidelines from 2001, has been monitoring and publishing data on material flow accounts since 2002. More recent methodological guides issued by Eurostat (2009, 2012) and the OECD (2008) have resulted in a certain level of standardization for ew-MFA.

In this context, footprints based on the physical flows of specific resources were developed. For example, the method of Global Land Use Accounting (GLUA) was developed at the Wuppertal Institute (Schütz 2003, Schütz et al. 2003, Steger 2005, Bringezu and Steger 2005, Bringezu et al. 2008, Zah et al. 2010, Bringezu et al. 2012). It combines accounting of resource flows with the associated land use of a country or region to determine the global land area associated with the production and consumption of goods. In this method, a land use balance, similar to the material balance in ew-MFA or the trade balance in conventional economic accounts, is established. Consumption is calculated by adding national production plus imports minus exports. Basically, trade data (from e.g. the EUROSTAT COMEXT database) associated with commodity imports and exports are accounted for in terms of weight, more precisely in terms of mass (kg), and broken down into different material categories to calculate the land demands associated with trade. For agricultural primary products, the amount traded is combined with information on yields (kg/ha) based on e.g. FAOSTAT. For agricultural plant and animal products, land use coefficients (kg/ha) based on e.g. the Wuppertal Institute database (Schütz et al. 2003) are used. For this reason it is also known as a "coefficients approach". This is the approach applied in this paper and the method is described in more detail under materials and methods.

A number of studies have applied similar methods. For example, Erb (2004) used a similar approach to assess Austria's land footprint of arable land, pastures and forests between 1926 to 2000, finding that Austria is increasingly "appropriating" areas outside of its border, in particular, arable land and forests.

Van der Sleen (2009) used a similar accounting approach to answer the question "where and how much land is the EU using outside of its territory?" Van der Sleen examined the trade of 144 crops for every year between 1995 and 2005 for the EU-27. Only unprocessed (raw) crops were taken into account and data stemmed from Eurostat (for trade) and FAOSTAT (for yields). Van der Sleen found that the EU's net foreign land demand in 2005 was 14.1 Mha, or in other words, only 75% of the total demand could be met on domestic territory.

Von Witzke and Noleppa (2011) also quantified the amount of "virtual" land the European Union required in third countries for agricultural purposes between 1999 and 2008. They examined 240 categories of tradable products (including meat, cotton, wools, beverages and tobacco, etc.). Meat and dairy products were converted into crops using feed ratios and feed mix percentages and processed products were converted into agricultural raw products using conversion factors based on a number of sources including e.g. FAO (2001) and USDA (1992), as well as past studies (e.g. Steger 2005 and Van der Sleen 2009). Some products, such as spices and the products in the "confidential" and "miscellaneous" SITC (Standard International Trade Classification) categories were excluded. The authors estimated that around 20% of the EU-27's agricultural trade were not included. The study found that between 1999 and 2008 virtual land exports decreased by 17% whereas virtual land imports increased by 15%. The EU required an additional, external area related to approximately one-third of its territorial arable area to supply consumption in 2008. A major cause of the significant growth in virtual land imports was the increased use of soybeans, and soybeans accounted for more than 50% of the virtual land net import in 2008.

Qiang et al. (2013) quantified the productive land area "hidden" in the crop trade between China and other nations from 1986 to 2009. They studied 116 different crop products grouped into six categories (cereals, oil crops, fruits and vegetables, sugars, fibres, roots and tubers) using data from FAOSTAT for both trade statistics and yield conversions and drawing conversion factors for processed products from FAO (e.g. FAO 2003) and related studies (e.g. Kastner and Nonhebel 2010). Qiang et al. (2013) found that the net balance of virtual land use linked to China's crop trade changed from net exports to net imports during the study period. In particular, a massive increase in imports of soybean caused a dramatic increase in the virtual land imports of China between 2003 and 2009. These imports were attributed to the growing need for feed to supply the intensive pig and poultry rearing systems that have expanded rapidly in China, connected to changing dietary patterns. While the authors found that China is still self-sufficient regarding agricultural production, imports are rapidly gaining ground and there is a need to take the increasing impacts of Chinese consumption on land resources abroad into account.

Bringezu et al. (2012) accounted for 773 commodities to calculate the global land footprint of the EU-27. This study builds on that analysis with a total number of 991 commodities accounted for over a longer time span (see methods and results below).

2.2 Accounting for consumption using input-output analysis

Input-output models integrate economic data for whole economic systems (one country or several countries) to show the interdependencies between the production (industries) and consumption (e.g. households, government, etc.) units that form a national economic system. As such, they are also based on the concept of the industrial metabolism (see above). Monetary input-output tables (MIOTs) account for the monetary flows entering (via imports), within and leaving (via exports) the economic system. This is the type of input-output analysis that most footprint studies apply (Giljum et al. 2013a). The scope of the MIOTs can be expanded by means of environmental extensions to account for environmental pressures exerted by production and consumption activities[4]. Between 1969 and 2010, 360 papers were published applying environmental input-output analysis, with the bulk of early papers focusing on energy and more recently expanding to other environmental pressures (Hoekstra 2010).

Many of the studies using an input-output approach to calculate land footprints seem to aggregate all types of land use (e.g. cropland, pastures and forests) for all world countries, or a large portion of world countries, in order to compare world consumption levels (e.g. Wilting and Vringer 2009, Lugschitz et al. 2011, Arto et al. 2012, Yu et al. 2013, Weinzettel et al. 2013, Tukker et al. 2014). This makes direct comparisons to the results of ew-MFA (see above) difficult[5]. This form of aggregation has also come under scrutiny and a recent review of land flow accounting methods and recommendations for future development (Bruckner et al. 2014) suggests calculating land footprints separately for cropland, grassland and forest land[6]. In this way differences in data (accuracy and availability) can be taken into account and results may have more direct implications for policy makers.

Wilting and Vringer (2009) were one of the first studies to apply a multi-regional input-output (MRIO) model to calculate land footprints. They aggregated the consumption of cropland, forests and built-up land into land footprints for 12 world regions. Data was sourced from the IMAGE Model (version 6), GTAP (Global Trade Analysis Project – showing crop production for 19 crops in 226 countries), and the UN and HYDE[7] database. The study pointed to disproportionate consumption levels in the world, with around 2 billion people (32% of world population) using almost 70% of the total land use for production and consumption, or on a per capita basis, using more than 1 ha/cap.

Arto et al. (2012) used the World Input-Output Database to analyze six environmental dimensions (including land footprints) between 1995 and 2008 for the EU-27, the BRICS and the United States. They also aggregated different types of land use into one land footprint and found that the EU-27 used 1.36 ha/cap in 2008. Pastures represented 41%, forests 32%, arable land 24% and permanent crops 3% of the EU's land footprint. In comparison, they calculated an average aggregated global land footprint of 1.07 ha/cap. Russia (4.83 ha/cap) and the US (2.69 ha/cap) were shown to be well over the global average while China (0.5 ha/cap) and India (0.19 ha/cap) were shown to be well under it.

Similar disparities were shown by Lugschitz et al. (2011), who applied a similar method and found that Australians had the highest aggregated land footprint in the world, and that Australians induced 150 times more land use than an average person of Bangladesh (which had the lowest land footprint). These results are consistent with the recent study on the "four footprints" (Tukker et al. 2014) using the EXIOBASE data set, which also show that Australia has the highest aggregated land footprint. Tukker et al. attribute this

[4] Environmental extensions can be accounted for both in physical and monetary units. Physical units are used to represented environmental pressures such as air emissions, resource/material use, etc. Extensions related to environmental taxes or environmental protection expenditure are given in monetary units (Giljum et al. 2013a).

[5] Note that some of the studies additionally present the land footprint disaggregated into different land types, which requires some additional calculations but does produce comparable results (see Table 1 below)

[6] This recommendation received broad support at the international expert workshop on "Improvement of the land footprint methodology through impact oriented land use indicators" workshop organised by Ecologic Institute on the 25th of June, 2014, Berlin.

[7] History Database of the Global Environment: The HYDE database is developed under the authority of the Netherlands Environmental Assessment Agency. URL: http://themasites.pbl.nl/tridion/en/themasites/hyde/

to extensive pastures in Australia. Yu et al. (2013) also used a MRIO model to account for the land use attributed to “unusual” sectors (like services, machinery and equipment and construction). They found that more than 50% of the land use of the EU is displaced from other countries, and that this ratio is even higher for other countries like Japan (over 90% displacement).

2.3 Land use targets

Research on land use targets is on-going. Studies suggest that establishing monitoring mechanisms for footprints at the national level is an important step forward, but targets are also needed to put these footprint levels into perspective (e.g. Bringezu et al. 2012, O’Brien et al. 2014). The question for land use is, what is a “sustainable” global land footprint now and in the future?

To this end, the concepts of planetary boundaries and safe operating space (Rockström et al. 2009a,b) have made important steps forward by addressing the question of a “sustainable” level of global land use change. Rockström et al. (2009b) write that “humanity may be reaching a point where further agricultural land expansion at a global scale may seriously threaten biodiversity and undermine regulatory capacities of the Earth System (by affecting the climate system and the hydrological cycle)”. They calculate that no more than approximately 15% of the global ice-free land surface should be converted to cropland, implying that an expansion of around 400 Mha (from 2005) would be within the safe operating space. Further studies have worked to translate this threshold to national targets. For example, Nykvist et al. (2013) suggest two options for translating global planetary boundaries into national targets for Sweden. First, they suggest an approach that divides the maximum area of cropland available by the world population, calculating a *current* reference value of 0.3 hectares per person Second, they suggest an alternative approach which considers the territorial land area of nations, suggesting to limit the national conversion of land to 15% of nationally available land area. However, the first approach neglects on-going trends to provide a future orientation and target, in particular considering future population growth expectations and the impacts on per capita targets. The second approach seems to be unsuitable for a globalized world characterized by vastly different nations, considering population density, natural conditions, structural development, etc., which may better maximize natural resource management and use through trade. For this reason, mid to long-term targets which relate to a consumption perspective are needed.

Bringezu et al. (2012) argue that in order to provide a long-term sustainability reference for consumption, land use targets must incorporate two components: (a) information on an acceptable level of resource use at the global level, and (b) an adequate attribution to the consuming countries.

As regards (a), they build on the concept of safe operating space and suggest that a strong sustainability target would be to halt global cropland expansion in the year 2020. This would imply a global land target of around 1,640 Mha (or approximately 12.6% of global ice-free land area) with the rationale based on halting the loss of biodiversity through land use change. While this boundary level is somewhat lower than the Rockström et al. (2009a,b) defined threshold, the study argues that continued expansion of “built-up” land (streets, urban-sprawl, etc.) will further displace cropland and consequently reduce the total amount of land “available” for cropland without encroaching on the threshold for land use change.

As regards (b), Bringezu et al. (2012) also suggest a per capita distribution of sustainably available cropland. They argue that despite different endowments of countries with fertile soils, rainfall, and growing conditions, as well as technological means, per capita consumption targets seem to be the most feasible way forward to provide an indication of sustainability regarding the scale of resource use, as well as to address the underlining drivers of cropland expansion and prevent problem shifting between biofuels, biomaterials and food. To this end, they note that markets for agricultural products are increasingly linked, technological capacities are expected to converge and that people worldwide should be entitled to an equitable share of resource supply, in particular as regards food security. Accompanying policies to reach such targets would include, for example, instruments to reduce food waste, support for increased efficiency across supply chains, support toward a sustainable level of biofuel consumption, and economic instruments to provide incentives for shifting diets toward more healthy and sustainable levels of meat consumption, among others. As a preliminary orientation Bringezu et al. suggest that 0.20 hectares per person could provide a medium-term target for the year 2030.

UNEP (2014b) adopted this suggestion to promote a per capita target of 0.20 hectares (1,970 m^2) in 2030. The year 2030 is chosen as a practical time period to distinguish the direction and order of magnitude of necessary adaptations. This paper will also consider the 0.20 hectares target as a comparison to current levels of EU consumption.

3 Materials and methods

The FAO classification of agricultural land types is used in this study (see for instance Marklund and Batello 2008). Thus, cropland includes land under temporary crops, meadows for mowing or pasture, gardens, and land temporarily fallow (less than five years) as well as permanent crops. For valid aggregation of national and transnational land use, categories of land use types – such as 'agricultural land' – need to be accounted for in a comparable and consistent manner. In general, compared to other world regions all the domestic agricultural land within the EU-27 can be considered intensively managed.

As regards imports and exports we distinguish 991 commodities by the 6-digits HS classification of the Eurostat Comext external trade statistics into primary crops (after the FAO classification), plant-based products, and animal-based products from agriculture. In that sense we update the time scope provided by Bringezu et al. (2012) and provide a more detailed analysis due to more comprehensive data availability. For imports of primary crops we apply the yield factors of FAOSTAT online, which are specific by country of origin of imports and by year, while for exports of primary crops we use weighted yield factors from domestic production and imports. This seems justified as traded flows are usually minor in relation to domestic production, and transit flows are the exception[8]. In general, yields for agricultural animal or plant products were taken from the database of the Wuppertal Institute (Schütz et al. 2004; Bringezu et al. 2012; and updates). For plant-based products we apply largely

[8] ComExt excludes goods in simple transit, temporary trade, trade not subject of a commercial transaction. References are: "Annex I of the Commission Regulations (EC) No 113/2010 (Extrastat)" and "Commission Regulation (EC) No 1982/2004 (Intrastat)".

productivity figures relating to the domestic production in Germany derived from supply balances and production statistics of the German Ministry for Agriculture, as well as conversion coefficients (e.g. amount of flour per unit of wheat) and data derived from product specific LCA studies (e.g. Diers et al. 1999) and generic sources such as USDA (1992, 2005). For animal products we apply mainly productivity figures derived from feedstuff statistics – differentiated by domestic and foreign origin – and production statistics of the German Ministry for Agriculture for calculating the land use associated with imports and exports. As we use German-based statistics we thus implicitly estimate that processed goods are produced in intensively managed systems across the globe. This may be quite realistic considering that crops (and derived products) for export are most likely from intensively used land, rather than from areas with marginal yields, but it may also underestimate the amount of international land required. The case of grassland is more difficult because grasslands in the EU are intensively used, whereas in other parts of the world use is extensive. Unpublished data from the Netherlands Environmental Assessment Agency for intensively managed grasslands globally [9] enabled us to calculate the global intensively managed agricultural area. We thus consider trends for two categories of agricultural land use for this paper: cropland and intensively managed agricultural area (the latter consists of cropland plus intensively used grasslands, where cropland is arable land plus permanent crops).

The agricultural land use for imported biomass products was in the first place calculated as total land required for the production of those products. For example, the land to grow rapeseed for extraction of oil was allocated completely to "rapeseed oil". We call this land requirement "gross production land". Accounting for the agricultural land required for the consumption of agricultural goods we calculate "net production land". In this case, land is allocated to several products derived from the crop harvest. In our example, the land needed to grow rapeseed for oil is allocated to different products produced on the same land, i.e. to oil and to rape-oilcake for animal feed (on the basis of the weight). This procedure avoids double-counting for the total global agricultural land use for consumption of all agricultural products (Bringezu and Steger 2005).

For this reason, we calculate global land use for all imported (and exported) agricultural commodities on the basis of net production land. Adding the domestically used agricultural land to the net land requirement of foreign trade (imports minus exports) provides the global land use for domestic consumption of agricultural goods in the EU-27 ("net consumption land").

This scope of this study is the EU-27, instead of the EU-28, because data is more widely available for the EU-27 over a longer time period. In general, it should be noted that results for the EU-28 are close to those of the EU-27 (see Figures 2-5). The time period assessed covers the years 2000 to 2011. Trade data are available until 2013, so that while some figures show data until 2013, the analysis of trends is performed up to the year 2011 for the sake of comparability to production statistics. Finally, while this study assesses trends for both the agricultural land use and cropland requirements of the EU-

[9] By email communication with Stehfest, E., PBL/NL, on 30 August 2010 with reference to Goldewijk et al. (2007). Based on grassland productivity modeled by the IMAGE crop model, the authors classified grasslands into intensive and extensive pastures. Data for total grassland are in line with FAOSTAT data for permanent pastures and meadows. Reference to the productivity level definition of extensive and intensive grassland is in Bouwman et al. (2006).

27, it only presents data on the cropland footprint of the EU-27 to make results comparable to both other studies as well as targets.

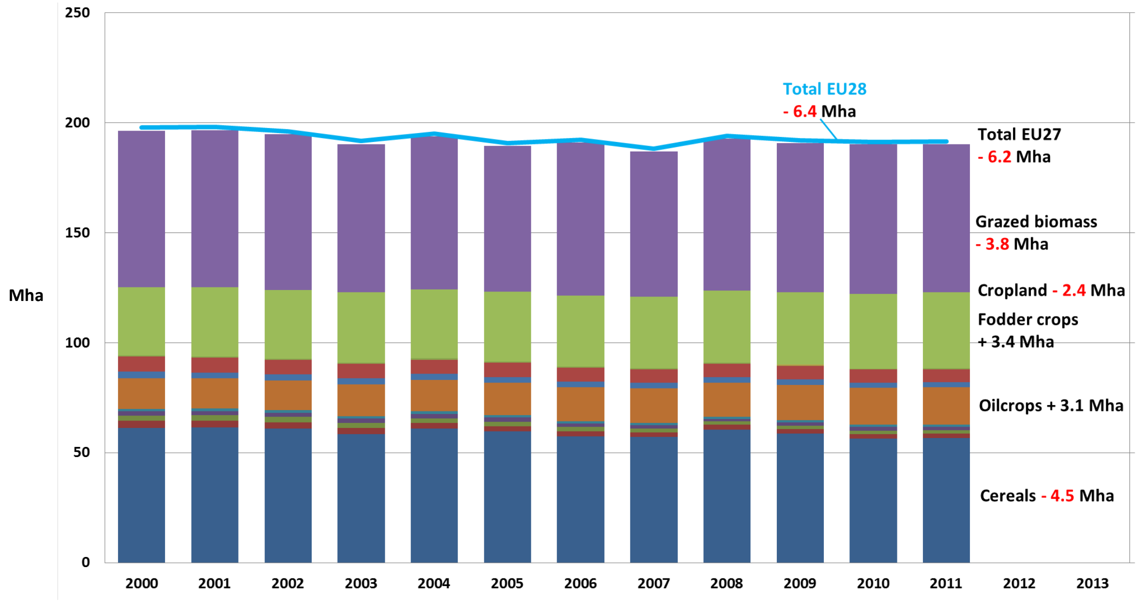
4 Results

Trends for domestic land use and for the pattern of imports and exports of commodities coming from agricultural land, as well as trade-offs between them, determine the pattern and magnitude of global land use for domestic consumption of agricultural goods. The results section presents these basic components of global land use accounting, and puts the results into the global context by comparing per capita values of available cropland and targets. This provides an example of the type of monitoring systems that countries or regions (like the EU) could implement to monitor global land requirements and to identify hot spots (e.g. for improving land use efficiency or biomass use efficiency). Results from this study are further compared with those from other studies and the basic underlying methodologies are compared with regard to strengths and weaknesses.

Domestic land use

Agricultural land area in the EU-27 covered around 187 Mha in 2011, comprising cropland (ca. 119 Mha) and permanent meadows and pastures for grazing (ca. 67 Mha). Within the EU-27 domestic agricultural area and cropland decreased from 2000 to 2011 by 6.2 Mha (-3.2%) and 2.4 Mha (-6.6%) respectively (Figure 2).

Figure 2: Agricultural area in the EU-27, 2000 to 2011 (Mha)



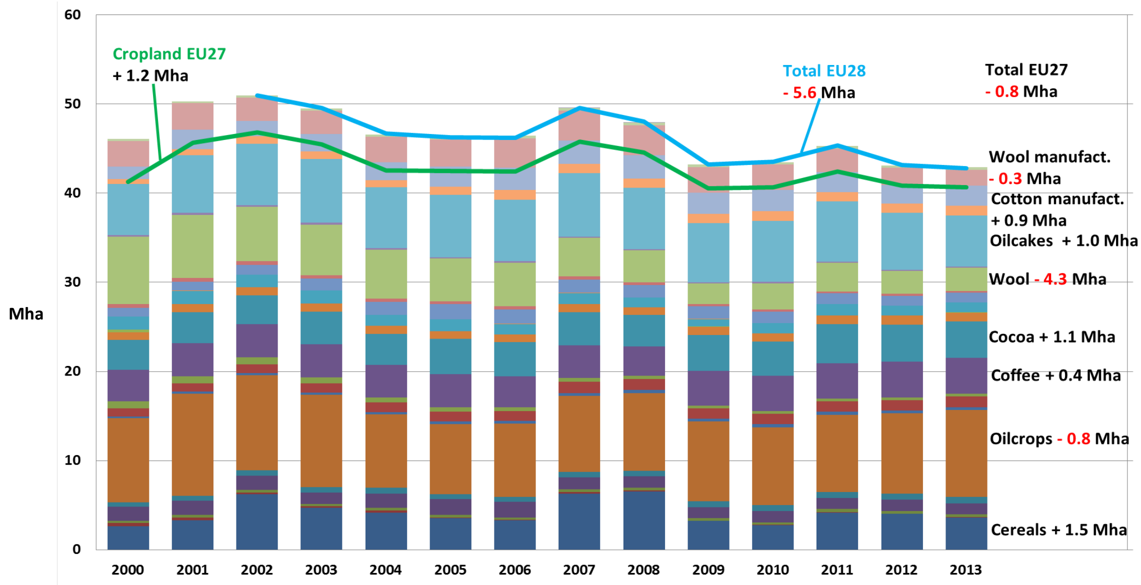
Source: H. Schütz, WI, based on FAOSTAT

Major trends from 2000 to 2011 include significant decreases of pasture land (grazed biomass) and cropland for cereals, while cropland for fodder crops and oil crops increased. The picture thus documents shifts in agricultural production due to intensification and setting of economic incentives.

Land use for imports

The EU-27 required ca. 45 Mha of agricultural land abroad for its imports in 2011, of which ca. 42 Mha were cropland (Figure 3). There is quite some fluctuation in the extent of “imported” agricultural area and cropland, and the overall effects from 2000 to 2011 are a slight decrease for agricultural land (-1.7% or -0.8 Mha) and a slight increase for cropland (+2.9% or +1.2 Mha). Mainly land requirements for oil crops and wool decreased from 2000 to 2011 while land requirements for imported cereals, cocoa, coffee, oilcakes, and cotton increased. However, fluctuations are rather high and some trends are not continuous.

Figure 3: Agricultural area associated with imports of the EU-27, 2000 to 2011 (Mha)

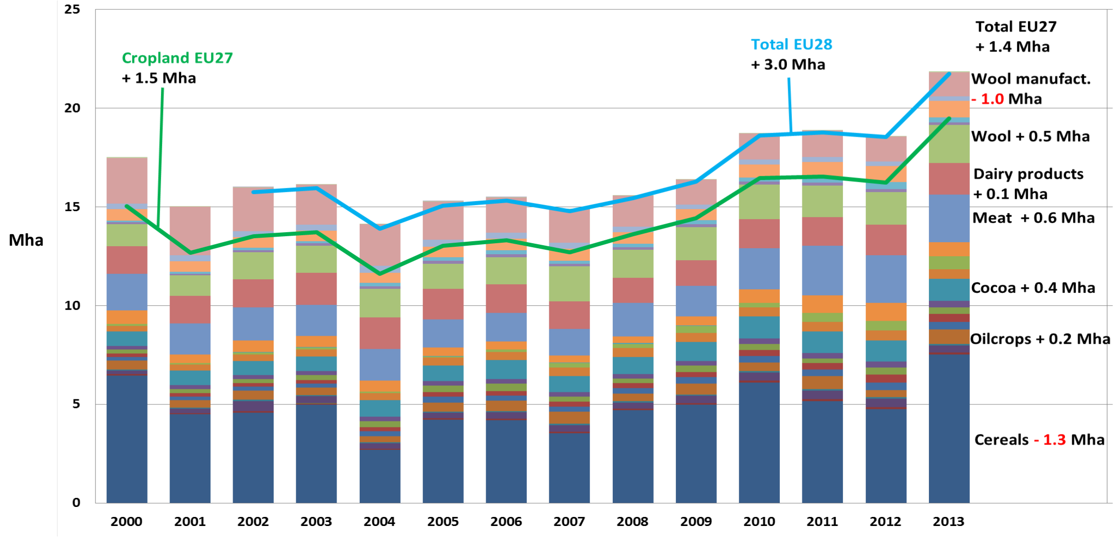


Source: H. Schütz, WI, based on Eurostat ComExt, FAOSTAT, own data base

Land use for exports

In 2011 the EU-27 “exported” ca. 19 Mha of agricultural land in total, of which ca. 17 Mha were cropland (Figure 4). There is an increasing trend in the extent of exported agricultural area and cropland, and the overall effects from 2000 to 2011 are an 8% (+1.4 Mha) increase for agricultural land and 10% (+1.5 Mha) increase for cropland. The land requirements for mainly oil crops, meat, dairy products and cocoa products increased from 2000 to 2011 while the land requirements for exported cereals and wool decreased. However, as observed for imports, fluctuations are rather high and some trends are not continuous.

Figure 4: Agricultural area associated with exports of the EU-27, 2000 to 2011 (Mha)

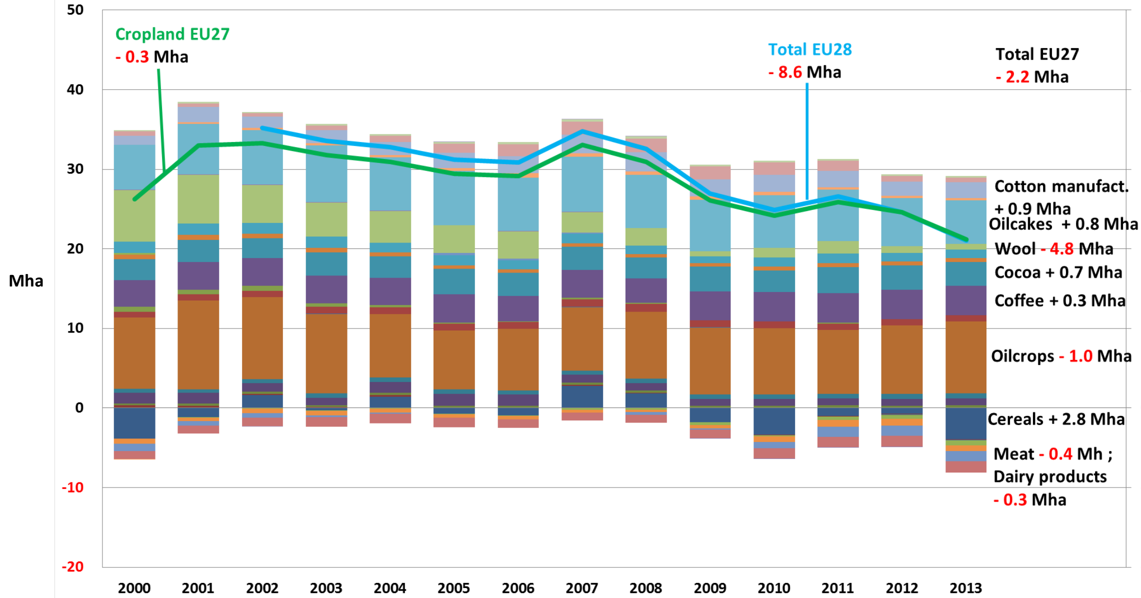


Source: H. Schütz, WI, based on Eurostat ComExt, FAOSTAT, own data base

Land use for net trade

The EU-27 is a net importer of agricultural land. Net imports prevailed over the period 2000 to 2011 but declined by -7.6% (-2.2 Mha) for agricultural land and by -1.2% (-0.3 Mha) for cropland (Figure 5). The ratio of net imports to net exports (of agricultural land) was highly variable and increased from 5.5 in 2000 to a maximum of 22.7 in 2007, but fell afterwards to a minimum of 3.6 in 2013. This underlines that the EU-27 has increasingly become an exporter of agricultural goods for global markets in recent years. The land requirements associated with net imports are mainly caused by oil crops, coffee, cocoa, wool, oilcakes and cotton. The land requirements associated with net exports are mainly due to meat, dairy products and cereals. Results for net land use by international trade of the EU-27 are in general very similar if cropland alone is looked at (instead of total agricultural area).

Figure 5: Agricultural area associated with net trade of the EU-27, 2000 to 2011 (Mha)



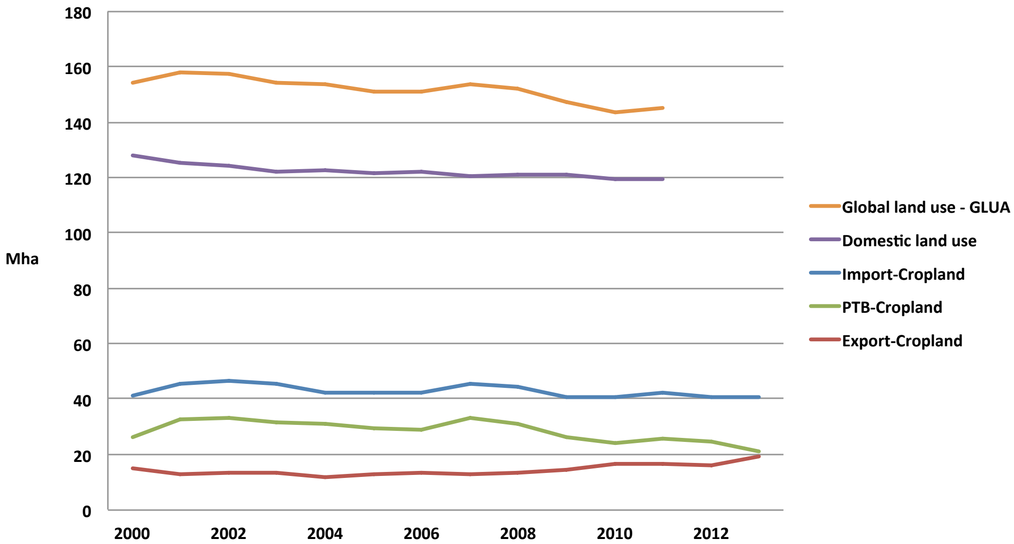
Source: H. Schütz, WI, based on Eurostat ComExt, FAOSTAT, own data base

Land use trends and GLUA

Global cropland use of the EU-27 ranged from around 158 Mha in 2001 to 144 Mha in 2011. There was a slight decline over the period, i.e. by -5.7% or -8.8 Mha (Figure 6). A decrease in domestic cropland area had the most expressed effect on the global cropland use of the EU-27, decreasing by -6.6% from 2000 to 2011 (from 128 Mha to 119 Mha).

Import and export cropland requirements both increased over the time period studied, but exports increased at a higher rate (+10%) than imports (+ 2.9%). As a consequence, even in absolute figures cropland requirements for exports increased more than those for imports (+1.5 Mha compared to +1.2 Mha respectively). The result for net import cropland area was a decline by -1.2% from 2000 to 2011. Worldwide cropland area (not shown in Figure 6) increased slightly from 2000 to 2011 by 38.6 Mha or 2.6%.

Figure 6: Global cropland use of the EU-27, 2000 to 2011 (Mha)



Source: H. Schütz, WI, based on Eurostat ComExt, FAOSTAT, own data base
Note: PTB stands for physical trade balance

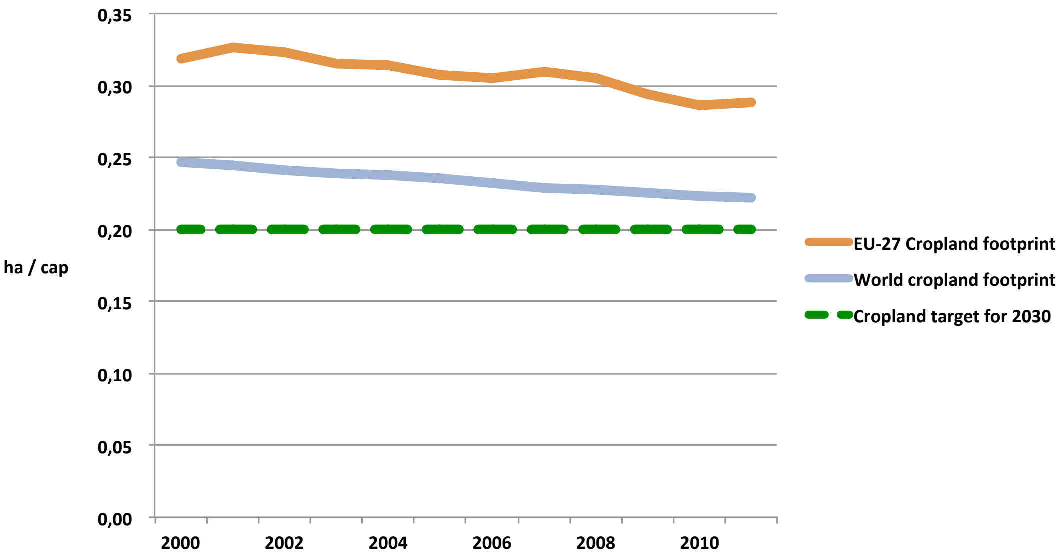
Cropland footprint and global land use targets

The cropland footprint of the EU-27 ranged between 0.32 and 0.29 ha/cap over the study period. The global availability of cropland on a per capita basis (the "world cropland footprint" in Figure 7) ranged between 0.25 and 0.22 ha/cap between 2000 and 2011. This means that the EU-27 used between 28% and 35% more global cropland per person than the world population on average, with a slightly declining trend of -9.4% from 2000 to 2011. Moreover, the EU-27 used between 20% and 27% more global cropland per person than domestically available, with a slightly declining trend.

The available cropland per person of the world population decreased over the study period by -10.2%. Incidentally, though somewhat in contrast to the EU´s footprint, this is almost the same rate as the per person decrease of domestic cropland availability in the EU-27 (at -10.3%). While per person domestic cropland availability in the EU-27 declined due to declining land area and increasing population, world cropland availability per person declined despite an increasing cropland area because these gains were offset by a higher increase in population. The footprint of the EU-27, however, declined only slightly less than the global per person availability (-9.4%), indicating a continuing disproportionately high consumption of global cropland use by EU citizens.

To reach the 2030 target of 0.20 hectares per person the EU would have to further decrease its global cropland footprint by around -30%. This would imply that an annual decrease of roughly -2% is needed until 2030. In comparison, the annual cropland footprint decreased by around -1% over the last decade. In the second half of the last century, yield gains have been effective to compensate increased demands (e.g. due to population growth) without requiring *much* extra land. However, in the future most studies expect a slow down of yield gains (see UNEP 2014b), meaning that the challenge for lowering the EU's global land footprint must be met with other measures (such as increased efficiency, reduced waste, and lower levels of consumption).

Figure 7: Cropland footprints of the EU-27 and world compared to the 2030 target, trends between 2000 to 2011 (hectares per person)



Source: H. Schütz, WI, based on Eurostat ComExt, FAOSTAT, own data base

Comparison of results from different studies

A comparison of results from different studies regarding cropland footprints is shown in Table 1. While some differences are expected due to the different geographic scope (e.g. EU-25 versus EU-27) as well as time frame (e.g. 2004 versus 2007/2008 versus 2011), the results from this study generally are in the same order of magnitude when compared to other economy-wide material flow analysis accounting approaches and also seem to be converging with input-output accounting approaches for cropland. Key differences are apparent in the accounting of trade statistics. As regards the former, this is due to the different level of detail accounted for in trade statistics. As regards the latter, In general, input-output approaches work on the assumption that the product groups of the input-output system are homogenous, and thus can only approximate real land use. Nevertheless, all cropland footprint accounting methods show a current cropland use above the 0.20 hectares per person target.

Table 1: Comparison of trade flows, global cropland use and cropland footprints of the EU by different studies and accounting approaches

Study	Geographical scope	Crops accounted for	Year	Imports (Mha)	Exports (Mha)	Global cropland use (Mha)	Cropland footprint (ha/cap)
Accounting approaches based on economy-wide material flow analysis							
Van der Sleen 2009*	EU-27	144 crops, unprocessed raw crops only	2005	20.4	6.3	136	0.28
Bringezu et al. 2012	EU-27	773 commodities	2007	45.8	12.7	153.9	0.31
Von Witzke and Noleppa (2011)	EU-27	240 products	2007/ 2008	49	14.1	156.2	0.31
This paper	EU-27	991 commodities	2011	42.4	16.5	145.2	0.29
Accounting approaches based on input-output analysis							
Weinzettel et al. 2013, 2014 and Stehen-Olsen et al. 2012**	EU-25	-	2004			152	0.31
Bruckner et al. 2014	EU-27	-	2007	64	10	168	0.34
Arto et al. 2012	EU-27	-	2008			184	0.37

*recalculated on the basis of the study to make comparable to other results
**based on data supplied by Jan Weinzettel, personal communication

5 Discussion

This paper has shown that the tools to monitor global land footprints are developing rapidly. The method of global land use accounting is one approach, which has been further developed by this study to include a more detailed accounting of the commodities comprising the EU's global cropland footprint. While some differences to other accounting approaches remain, there seems to be a trend toward a convergence of results and a general consensus between studies concerning main trends and the needed direction of change. In particular, the EU is shown by all studies to use a disproportionately high amount of global cropland in comparison to the world average. The EU is also shown to use more territory than domestically available to supply its demand for agricultural products. Soybeans have contributed significantly to the growth of the land footprint as well as the share of demand met by trade (in the EU as well as China). The challenge is to reduce the EU's global land footprint to keep it within the safe operating space of planetary boundaries, and to understand how the demands of a growing bioeconomy can be met in a sustainable way.

Policy relevance of footprint accounting

So far, there seems to have been little exchange between the development of policy strategies like the *Bioeconomy Strategy* (EC 2012) and research activities on land footprint accounting. While the *Bioeconomy Strategy* recognizes the need for promoting sustainable land use and pursuing a harmonized approach to mitigating competition from different types of final demand (food, energy, industry, etc.) both at home and abroad, it does not seem to foresee the need for accounting methods to monitor land requirements nor for overarching targets to benchmark development. However, it is exactly these activities which will ensure that sustainability objectives can be met. It makes a lot of sense to strengthen research on global land footprint accounting and global land use targets in order to avoid a situation in the future similar to that faced by the biofuels industry and the policy arena today, where ambitious targets and quotas have been reduced or removed because of concerns regarding land use change, large-scale land acquisitions, and climate change. Wavering targets send a weak market signal and hinder innovation, whereas strong, long-term policy targets may set an overall direction for change and provide incentives for market players to eco-innovate (EIO 2013). The kind of innovation needed to reduce land footprints could manifest in a number of forms, which also go beyond technical solutions, i.e. from strategic partnerships to reduce food loss across supply chains to bottom-up movements like "slow food" which promote more healthy eating behaviors. Reducing land footprints do not necessarily mean a halt to the innovative bioeconomy. On the contrary, it would strengthen the call for smart and innovative approaches which do not simply multiply the traditional way of producing and consuming biomass, and therefore land. For example, the promotion of cascades (using biomass for a material first before recovering its energy content at its end-of-life) in parallel with the development of biorefineries focused in particular on organic waste re-use could be key steps toward a sustainable bioeconomy transition. Using organic waste, for example, allows to recycle the carbon to various products, including polymers, and technological carbon recycling (Bringezu 2014) may be regarded as an advanced facet of a bioeconomy. This implies that the achievement of sustainability objectives for the bioeconomy depends very much on *how* the bioeconomy is implemented. To this end, monitoring tools and targets are urgently needed on the progress of decoupling economic development from natural resource use and the extent and sustainability of its footprint.

Knowledge gaps and research needs: comparison of different approaches to account for land footprints

We have seen that some uncertainties in determining the global land requirements of the EU-27 are due to variations in results from different methodological approaches. The questions that arise are: which approach is more realistic, reliable, and suitable for monitoring and distance-to-target evaluation?

The answer is not straightforward as there are advantages and disadvantages to both approaches, making the end decision for applying one method instead of the other dependent on the specific research questions. Accounting based on monetary values, as in monetary input-output tables, has the principle advantage of full coverage for all economic activities, including service sectors. Accounting based on physical resource flows, as in this study, has the advantage of working with a high level of detail for goods, as well as a high specificity for biomass production. There is also a greater avoidance of distortions in economy-wide material flow analysis based approaches. However, it may not be possible to account for all products, especially highly processed products, due to lacking conversion values. In the case of input-output methods all sectors may be covered, but the risk of distortion is also high. This is because environmental impacts are related to the price of a product, but prices may differ dramatically (e.g. 5 dollars or 1 dollar for a loaf of bread). While the price difference may relate to quality, it does not necessarily reflect higher or lower environmental impacts (e.g. the 5 dollar bread does not require 5 times as much land) (Kastner et al. 2014). A comparison of studies calculating land footprints for China (Kastner et al. 2014) pointed to widely different results using the two approaches: China shows strong net imports using accounting based on physical flows, but strong net exports using accounting based on monetary flows. This has dramatically different policy implications, in particular regarding the dependence on foreign land and food security for China. Whether the differences are a result of different approaches or different interpretations of results related to different definitions (e.g. one study looks at "bioproductive land" whereas the other at "actual land"), the example highlights the need to deepen research, make the assumptions of studies more explicit, compare the strengths and weaknesses of approaches and proceed towards standard definitions applicable for regular monitoring in order to produce comparable results.

One way to try and minimize the risks of both approaches and exploit the strengths is to apply so-called hybrid environmentally-extended multi-regional input-output models, which trace the primary biomass products in physical units through environmental extensions (e.g. Weinzettel et al. 2014). So far, more experiences with this approach have been made with material or carbon footprints (see e.g. the review by Giljum et al. 2013a) while research for land footprints is starting (e.g. Weinzettel et al. 2014).

Recommendations for researchers to improve the land footprint approach

To improve the land footprint approach we have highlighted five recommendations:

- **Harmonize definitions --** greater coherence is not only needed across technical terms within the land footprint community, but also to strengthen coherence with other land sciences, in particular land use modeling;
- **Account for all products and sectors --** the value of land footprint accounting for policy makers is that it provides information about impacts related to the extent of land use (such as land use change), which means that the effects of all purposes of land use (food, fuels, material, etc.) need to be monitored together. Accompanying tools may be additionally used to assess the land use intensity of different crops and product groups;
- **Account for major land types separately –** in order to account for large differences in environmental quality, potential policy leverage and data availability, cropland, pastures and forests should be accounted for separately. Research to strengthen approaches for forest and pasture footprint accounting are needed;
- **Anticipate future data challenges –** in particular associated with innovative products of the bioeconomy, like bio-based chemicals and plastics, to strengthen work on coefficients for accounting based on economy-wide material flow analysis, including the effects of recycling;
- **Strengthen knowledge exchange**: comparisons of the different approaches and the potentials of a so-called hybrid approach should be deepened to better understand methodological challenges (like the inclusion of multiple cropping), differences in results, and the most applicable methods for providing policy-relevant statistics.

Recommendations for policy makers to improve global land use monitoring

In general, three recommendations for policy makers to improve global land use monitoring may be distinguished:

- **Establish an international expert task force to discuss and solve critical methodological issues --** The ground for methodological and practical guidelines for establishing land footprint accounts by authorities like national statistical institutions (NSIs) should start to be prepared. This could lead to a legal base for reporting by NSIs. The proposed procedure would be similar to the successful implementation of economy-wide material flow accounts (ew-MFA) in the 28 EU member countries and beyond, facilitated by the statistical office of the European Union – Eurostat – and its task force on ew-MFA;
- **Integrate GLUA or land footprint accounting into official accounting routines at national authorities** -- A procedural way forward could be to proceed towards integrating such methods in official routines, while at the same time achieving alignment with the system of economic-environmental accounting;
- **Set global land use targets** – Targets which provide an indication of whether consumption is within the safe operating space of planetary boundaries are urgently needed to benchmark progress toward a sustainable, low-carbon and resource-efficient bioeconomy in the EU.

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