Reducing global land scarcity with floating urban development and food production

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Abstract
Rapid urbanization, rising food demand, land degradation and increasing biofuel demand will put pressure on available land. These global trends are evaluated by a survey of available documented literature to estimate global land shortage in 2050. An overview is presented of existing options to deal with the expected shortage of land including increasing agricultural production, urban densification and city expansion into floodplains. The article evaluates if floating urban expansion and floating food production can contribute to a solution for global land shortage. The results include an evaluation of the space use efficiency of floating city expansions and food production. The conclusion of the article is that floating developments can be a promising solution to global land scarcity, especially if a symbiosis is created between cities on land and floating developments on water. This symbiosis is achieved using waste nutrients and CO_2 for the production of food and biofuel in floating cities, with the application of floating algae systems. This approach closes nutrient and waste cycles and can provide ecological services to coastal cities.

Keywords
Land scarcity; floating urbanization; water-food-energy nexus; coastal cities; climate adaptation

INTRODUCTION

Increased food consumption by a growing human population presents large challenges for agriculture, which are amplified by the effects of climate change, land degradation and declining resources such as fresh water, phosphates, fossil fuels and fertile topsoil. Over the next decades, annual crop yield is projected to grow with less than 1% and there is very limited space for expansion of arable land (Alexandratos & Bruinsma, 2012). Future fresh water scarcity will put additional restraints on agricultural development (Hanjra & Qureshi, 2010). At the same time urbanized land is likely to double by 2030, in order to accommodate economic development and another 1.5 billion people moving to cities (Seto, et al., 2012). The largest proportion of these new city dwellers will live in vulnerable floodplains and it is estimated that, by 2050, half of the world population will be living within 100 kilometres from the coast (Adger, et al., 2005). In order to mitigate the effects of climate change, biofuel production is regarded as a vital solution to reduce emissions, but its expansion may compete with food production. In addition, the ecological footprint of converting biomass to ethanol is relatively large compared to the benefits of the net energy production and carbon offset (Dias de Oliveira, et al., 2005)

While much work has been done in the various fields on projecting how these trends may affect future food security, energy production and land use, an integrated view on future consequences for land use and possibly shortages is still lacking. This article evaluates how population growth, shifting consumption patterns and urbanization leads to land shortage, and investigates whether floating expansion can provide additional urban and agricultural space.

METHODS

An extensive literature survey was executed to evaluate relevant global trends in agriculture, land use, demographics and food and energy consumption, in order to estimate land shortage in 2050. The following area types and processes were taken into account: 1) Urban area; 2) Food production area; 3) Biomass production area; 4) Climate change impacts; 5) Land degradation. Studied literature includes those of relevant intergovernmental agencies such as the Food and Agricultural Organization (FAO), United Nations Environment Programme (UNEP) and International Energy Agency (IEA), in addition to relevant scientific literature. In order to deal with the uncertainty of future predictions and create an envelope of possible futures, two different scenarios were developed: a low scenario in which emissions and deforestation are minimized under moderate consumption growth conditions, a high scenario which is dominated by climate change, resource scarcity and high energy and consumption growth.

Urban area

Various sources have attempted to find the global urban extents, but they differ by an order of magnitude (Table 1). In our high and low scenarios of urban area, studies that are known to under- or overestimate the total urban area were not taken into account. Underestimation is the case with GLC2000, Globcover and VMAP (Bontemps, et al., 2011; Potere, 2009) Overestimation is found in GRUMP, as it is based on night-time lights that are known to cause blooming effects. Therefore, based on the above considerations, current urban extent is estimated at 1,000,000 km²; roughly the mean value of the studies taken into consideration. Projections for future urban areas were based on Seto et al. (2012) who investigated the expected urban growth to 2030 based on IPPC SRES scenarios. A conservative estimation was made to extend this for the period of 2030-2050, including only the projected additional urban population (UN, 2012). As a result urban expansion towards 2050 is expected to be between 2.35% p.a. (A2) and 3.36% p.a. (A1). These values are comparable with other findings. Angel et al. (2005) studied historic patterns of density decline in a large sample of cities, and at 1-2% decline the increase of land is estimated between 2.34% and 3.37% p.a.

Table 1. Estimation of global urban area according to various sources, extending Schneider et al. (2009)

Abbreviation	Map (citation)	Definition of urban	Resolution	Extent (km²)
VMAP	Vector Map lvl 0 (Danko, 1992)	Populated places	1:1 mil	276 000
GLC2000	Global Land Cover 2000 (Bartholome & A, 2005)	Artificial surfaces and associated areas	988 m	308 000
GlobCover	GlobCover v2.2 (Bontemps, et al., 2011)	Artificial surfaces and associated areas (>50%)	309 m	313 000
HYDE	History Database of the Global Environment v3 (Goldewijk, 2005)	Urban area (built-up, cities)	9000 m	532 000
IMPSA	Global Impervious Surface Area (Elvidge, et al., 2007)	Density of impervious surface area	927 m	572 000
MODIS 500m	MODIS Urban Land Cover 500 m (Schneider, et al., 2009)	Areas built (>50%) with mapping unit >1 km², incl. non-vegetated/constructed elements	463 m	657 000
MODIS 1 km	MODIS Urban Land Cover 1 km (Schneider, et al., 2003)	Urban and built-up areas	927 m	727 000
MOD12-a	MOD12 adjusted for UN urban population (Munesue & Masui, 2010)	Urban and built-up areas, population		1 120 000
GLP	Comprehensive global 5min res. land-use data set for 2000 (Erb, et al., 2007)	Infrastructure land use	5 min	1 360 000
PMUe	Mapping global urban and rural population distrib. (FAO, 2005).			2 210 000
GRUMP	Global Rural–Urban Mapping Project (CIESIN, 2004)	Urban extent	927 m	3 524 000

Food production area

The additional area required to satisfy food demand in 2050 depends on how well crop yields and cropping intensity developments can keep up with population growth and consumption patterns that shift from staples towards vegetables, fruits and animal products. Based on GDP projections, Tilman et al. (2011) forecast 100-110% increase in global crop demand by 2050. Alexandratos & Bruinsma (2012) project a lower increase of ~60%, but under current population growth projections (UN, 2013b) this estimate is only likely when shifting diet patterns are compensated by a considerable reduction in food waste and losses, which currently accounts for 24% of the calories produced (Kummu, et al., 2012). Therefore this projection was taken as a low scenario. The required additional land area for croplands was calculated with an expected agricultural productivity increase of 1.1% p.a. until 2050 (Alexandratos & Bruinsma, 2012). For pastures, the increase of required land area was based on studies from Tilman et al. (2001) for the low scenario and research of the International Water Management Institute (de Fraiture, et al., 2007) for the high scenario.

Biomass production area

Future energy production will reflect the growing population and increased overall prosperity. At the same time emissions need to be reduced by 50% to 85% compared to current levels to mitigate climate change (IPCC, 2007). To be able to achieve this goal, a considerable contribution is required from biomass for heat and power generation and liquid biofuel for transportation (Powell & Lenton, 2012; IEA, 2012). Current ethanol production is estimated at 2.0 EJ, from a feedstock consisting of 415 million tonnes food, produced on an area of 14 Mha (FAO, 2012). It consumes about 5% of the total global crop production. A smaller amount of biodiesel is produced, but with similar yields of ~0.13 EJ/Mha.

According to projections by the International Energy Agency, the 50 EJ biomass produced today needs to be increased to 160 EJ by 2050, including 60 EJ of biofuel (IEA, 2012). Alternative sources of biomass, including agricultural wastes and residues, may account for ~30 EJ (Van Vuuren, et al., 2010; Ladanai & Vinterbäck, 2009; McKendry, 2001; Marshall & Sugg, 2008; Lal, 2008), which implies that traditional biomass needs to be increased by about 30 EJ and biofuel production by 57 EJ. The low and high scenarios were based on different yield projections. The high scenario was based on average crop yield projections for 2050 (Alexandratos & Bruinsma, 2012). The low scenario was based on the assumption that the introduction of new technologies could double the efficiency of biomass production and conversion by 2050.

Climate change impacts and land degradation

Climate change will also impact agricultural productivity and thus the expected land scarcity in 2050. To develop the high and low scenario for additional land requirements due to productivity loss, data from the IFPRI study (Nelson, et al., 2010) was used which analyses climate change effects on maize, rice and wheat. Land degradation leads to decreased agricultural production and eventually land abandonment. Various authors have studied the total agricultural land area and estimate that between 4 and 12 million hectares p.a. lost due to degradation (Pimentel, 2006; Boelee, et al., 2011; UN, 2013a). The bandwidth of these estimations was used for the two scenarios.

RESULTS

All the different land use functions and processes were added together to estimate the low and high estimation of global land scarcity in 2050. The result is shown in Table 2 which shows that the additional land requirement in 2050 is 13 million square kilometres in the low scenario and 36 million square kilometres in the high scenario. If these results are compared with the total global productive land area (110 million km²), the total global forest area (40 million km²) or with the total land area of a large country such as China (9.6 million km²), an idea can be obtained about the magnitude of the expected land shortage.

Table 2. Additional land requirement per function or process in 2050 for low and high scenarios.

	Low scenario (10^6 km^2)	High scenario (10^6 km^2)
Urban area	1.5	2.8
Food production area	6.0	22.1
Biomass production area	3.4	4.3
Climate change impacts	0.7	1.7
Land degradation	1.6	4.8
Total land shortage	13.2	35.7

The additional land shortage could be accommodated in various ways. Additional productive land could be found by converting forests into agricultural land, but this would require a significant amount of the current nature area; 32% in the low scenario and 89% in the high scenario. Further intensification of agricultural production may be an option for the short term, but could eventually lead to excessive land degradation. Reducing the calorie intake, changing diets to more vegetarian lifestyle or birth control could also reduce the land shortage, but may be difficult to achieve and could lead to social problems. Therefore in this article, it is evaluated to what extent the land shortage can be accommodated by floating developments on the water.

DISCUSSION

The total area of the seas and oceans on the planet amounts to 361 million square kilometres (or 70% of the planet). The amount of space is therefore enough to accommodate additional land requirements towards 2050. Creating floating cities is a potential and technically feasible option to accommodate the urbanization process (De Graaf, 2012). However, creating floating cities would only provide about 12% of the total land shortage of table 2. Therefore the possibility of producing food and biofuel on the sea should be included to be able to provide a feasible alternative.

Food production on the water

Fisheries and aquaculture already supply the world with about 148 million tons of fish. Of this amount 40% of the world fish production in 2010 came from aquaculture (FAO, 2012). Since catches from wild fisheries may already be 2-3 times larger than what the oceans can sustainably support (WWF, 2013), farmed fish production needs to increase in order to meet growing human food demands. However, growth of aquaculture industry increases pressure on natural resources such as water, energy, feed and even land. Smil (2002) compared fish feed conversion ratio (kg of feed/kg-1 of edible weight) to that of livestock and livestock products and found that chicken, pork and beef are 1.5, 4.0 and 8.5 times less efficient. Production of microalgae, which can serve as feed (Bell & Waagbo, 2008; Tartiel, et al., 2008), would be 20-140 times more efficient in terms of space than producing soy as feed for livestock (USDOE, 2010).

Biofuel production on the water

In recent years, great attention has been devoted to the use of algae to produce biofuels, food, feed and other by-products. Algae are efficient organisms capable of taking carbon and synthesize it into a high density liquid form of energy (natural oil) while at the same time extracting inorganic nutrients from the water. Potential yields are of microalgae are estimated to be 5 to 60 times higher than yields of oilseed crops and water consumption 150 to 300 times less (USDOE, 2010). Growing algae to produce biofuel can be 10 to 20 times more productive compared to corn or sugarcane. On average the productivity is 15 times more efficient. The protein content of algae biomass varies from 10% to 70%, with an average of 40%, comparable to meat and soy (Gouveia, et al., 2008). Because of their well balanced chemical composition, algae can also be used as food for humans, feed for fish and other animal. Protein from residues of biodiesel and ethanol feedstocks can be used to feed aquaculture animals, but also for livestock. The quantity of algae (microalgae biomass) that can be fed to terrestrial animals varies: chicken can be fed with 5%-10% algae in their feed, whereas pigs can eat up to 25%-35%. Ruminants on the other hand cannot digest carbohydrates contained in algae and therefore algae biomass cannot be directly fed to them (Gouveia, et al., 2008). Floating algae systems also provide opportunities to create a symbiosis between cities on land and water. This symbiosis can be achieved by using waste nutrients and CO_2 of land based cities for the production of food and biofuel in floating cities, with the application floating algae systems. This approach closes nutrient and waste cycles and can provide ecological services to coastal cities.

CONCLUSION

Urbanization, a growing demand for food and biofuel, climate change and land degradation are expected to lead to a shortage of land in 2050. This article presented two scenarios to estimate the global land scarcity in 2050. In the low scenario the global land shortage is estimated at 13 million km^2. In the low scenario, the global land shortage is 36 million km^2. This article evaluates whether floating urban development and floating agriculture at sea may present a solution to the problem of global land scarcity. Based on studied literature sources, it was found that food and biofuel production on water can be >10 times more efficient per surface area unit. Cities can be constructed on the water with the same density as cities on the land. Because of the higher efficiencies the amount of space on the sea that is required to solve the global land shortage in 2050, is much lower than on the land. In the low scenario in 2.4 million km^2 is needed on the sea to solve the land shortage. This corresponds to 0.7% of the total ocean surface. In the high scenario 5.4 million km^2 is needed which is equal to 1.5% of the total ocean surface. Therefore, it may be concluded that the construction of floating urban development and floating food production are a potentially promising solution to the expected problem of global land scarcity.

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