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Biofuels and implications for agricultural water use: blue impacts of green energy

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Abstract

Rising energy prices, geopolitics and concerns over the impact of greenhouse gas emissions on climate change are increasing the demand for biofuel production. At present biofuel production is estimated at 35 billion liters, accounting only for a small part (~2%) of the 1200 billion liters of annual gasoline consumption worldwide. But the contribution of biofuels to energy supply is expected to grow fast with beneficial impacts including reductions in greenhouse gasses, improved energy security and new income sources for farmers. However, biomass production for energy will also compete with food crops for scarce land and water resources, already a major constraint on agricultural production in many parts of the world. China and India, the world's two largest producers and consumers of many agricultural commodities, already face severe water limitations in agricultural production, yet both have initiated programs to boost biofuel production. This paper explores the land and water implications of increased biofuel production globally and with special focus on these two important countries, using the WATERSIM model. It concludes that, although of lesser concern at the global level, local and regional impact could be substantial. In fact, the strain on water resources would be such in China and India that it is unlikely that policy makers will pursue biofuel options, at least those based on traditional field crops.

Keywords: Biofuels; Bio-ethanol; China; India; Water requirements; Water scarcity implications

1. Introduction: energy and water

Fluctuating energy prices affect agriculture, and thus agricultural water management, in different ways. The potential impact of higher energy prices on agricultural water use is fourfold. First, the demand for cheaper energy sources, including hydropower and energy from biomass rises, increasing water demand and changing water resource allocation. Second, the cost of pumping groundwater, a major factor in agricultural production around the world, increases. In addition, energy for groundwater

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use in some parts of the world, most notably India, is subsidized. Rising energy prices thus put additional pressure on government budgets and may lead to rising costs to farmers. In the Indian context this means making irrigation unaffordable to millions of small farmers. Third, when energy prices rise, the viability of desalinization as a source of irrigation and other water supply declines. Finally, fertilizer prices and the unit costs of other oil-based inputs rise with increases in energy prices.

Both hydropower and biomass require substantial amounts of water. Hydropower is largely a non-consumptive water user though there are some consumptive losses through evaporation from reservoirs and timing of releases may conflict with other consumptive uses. The production of biomass, on the other hand, is a consumptive use of water that may compete directly with food crop production for water and land resources (Berndes, 2002). At present the role of biomass in meeting energy demand is modest. Only 7% of total global energy supply comes from biomass, mainly wood, crop residues and dung (IEA, 2004a). Regional variation is substantial: in sub-Saharan Africa, where firewood for cooking is widely used, close to 60% of energy use comes from biomass, while in OECD countries the portion is only 2%[1].

With concerns over high energy prices, volatility of oil supply and greenhouse gas (GHG) emissions, energy derived from biological sources and in particular biofuels has received considerable attention (see for example IEA 2004a, b; Dufey, 2006). In particular, fast growing oil importing economies such as China and India are exploring biofuels to curb oil dependency. But to grow biofuel crops more land and water will be needed. Both China and India already suffer from water scarcity problems that will only worsen as their food demand continues to grow with rising populations and incomes. China is implementing a costly transfer project to bring water from the water-abundant south to the water-short north. India is exploring the possible implementation of a controversial multi-billion dollar project of inter-basin water transfers, to meet future demands. In both countries biofuels will add pressure to water resources that already are heavily exploited or overexploited. This paper looks into the implications of biofuel production on water use, with emphasis on China and India.

2. Biofuels production and use

Biofuels are transportation (or heating) fuels derived from biological sources such as grains, sugar crops, oil crops, starch, cellulosic materials (grasses and trees) and organic waste. There are two main types of biofuel: bioethanol and biodiesel[2]. The production of bioethanol, made from sugarcane, corn, beets, wheat and sorghum, was estimated at 32 billion liters in 2006. Brazil (using sugarcane) and the USA (using mostly corn and some soya) are the main producers, accounting for 70% of the global supply (Dufey, 2006). Biodiesel production, derived from oil- or tree-seeds such as rapeseed, sunflower, soya, palm, coconut or jatropha, was estimated at 2 billion liters in 2005 (IEA, 2004a). Three countries in Europe (Germany, France and Italy) produce nearly 90% of the global supply, primarily using rapeseed (Dufey, 2006). In South-East Asia interest in biodiesel derived from palm oil is growing.

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[1] Note that there is a difference between the broad term bio-energy (used in households, transport and industry) and the much more limited term biofuels, used as transport fuels for cars, buses and trucks.

[2] Both are typically mixed with conventional car fuel gasoline and diesel, respectively, so called flex-fuel. Blends vary between a few percent of biofuel to nearly 25% in Brazil.

Together, bioethanol and biodiesel account only for around 2% of the global annual consumption of 1200 billion liters of gasoline (in energy equivalents)[3] (Dufey, 2006). However, the contribution of biofuels to energy supply is expected to expand rapidly. Global bioethanol production doubled between 1990 and 2003 and has been projected to double again by 2010. In some regions, especially Europe, biodiesel fuel use has also increased substantially in recent years (IEA, 2004a). At present the biofuel supply and demand is dominated by the few big producers mentioned above (Brazil, USA and EU). But interest is rising among many countries around the world and many have put policies in place to spur biofuel production and use (IEA, 2004a).

2.1. Reasons to promote biofuels

Biofuels have been part of the energy discussions for decades. However, over the past few years, discussion and action has increased with rises in crude oil prices. But in addition to prices, there are a number of reasons why governments are showing interest in biofuels even when subsidies are needed to make them commercially viable. These include energy security, concerns about trade balances, desire to decrease GHG emissions and potential benefits to rural livelihoods (Dufey, 2006).

(1) Energy security—The volatility of world oil prices, uneven global distribution of oil supplies (75% in the Middle East), uncompetitive structures governing the oil supply (i.e. the OPEC cartel) and a heavy dependence on imported fuels leave oil importing countries vulnerable to supply disruption (Dufey, 2006). Recent interruptions in oil supply from Russia to Belarus because of political disagreements acutely illustrate this vulnerability. Biofuels are often seen as part of a strategy to diversify energy sources to reduce supply risks.
(2) Trade balance—Poor oil importing countries spend a large part of their foreign currency reserve to buy oil. Producing biofuels to substitute oil imports helps reduce the oil bill[4].
(3) GHG emission reduction—Many studies indicate that the use of biofuels reduces GHG emission compared with fossil fuels (IEA, 2004a) though the extent of reduction is disputed and depends on crop and production technology (Sims *et al.*, 2006; Farrell *et al.*, 2006). Some studies indicate that biofuel production generates more GHG than it saves in burning (Pimentel, 2003).
(4) Rural development and income generation—Biofuels generate a new demand for agricultural products, creating jobs in rural areas and increases in farmer income through higher commodity prices[5].

However, compared to fossil fuels, biofuels are still relatively costly (IEA, 2004a) though with the introduction of new more efficient techniques–such as the use of yeast (Alper *et al.*, 2006) and enzymes to produce lignocellulosic bioethanol–production costs may come down in coming decades. The oil

[3] The energy content of one liter of biofuel depends on the type but is typically estimated at 65% of that of fossil fuel (see also http://bioenergy.ornl.gov/papers/misc/energy_conv.html).
[4] For example according to an unofficial estimate Brazil's ethanol program saved the country US$18 billion foreign exchange over the period 1979–90. Langevin (2005) cites a number of US$1.8 billion per year between 1976 and 2000.
[5] Moreira (2005) estimates that sugarcane in Brazil (which directly relates to bio-ethanol production) employs 1 million workers.

price that would make biofuels competitive depends on many factors, including changes in the cost of producing, transporting and processing biomass. Estimates show that bioethanol in the EU becomes competitive when the oil price reaches US$70 a barrel (Dufey, 2006) while in the USA it becomes competitive at US$ 50–60 a barrel (Dufey, 2006) and in Brazil between US$25 and US$30 a barrel (Dufey, 2006). Other efficient sugar producing countries such as Pakistan, Swaziland and Zimbabwe have production costs similar to Brazil's (Dufey, 2006). A further possibility is that biofuels could become competitive if they are used to offset GHG emissions (Parikh & Gokarn, 1993). At present, the development and promotion of biofuels are mainly driven by the agricultural sector and green lobbies rather than the energy sector (IEA, 2004a). In fact, most biofuel programs depend on subsidies and government programs, which can lead to market distortion and is costly for governments[6]. Nevertheless, at sustained high oil prices and with a steady progression of more efficient and cheaper technology, biofuels could be a cost-effective alternative in the near future in many countries.

2.2. Concerns about rapid biofuel growth

There are important implications for a possible large scale development of biofuel. Two often raised concerns relate to impact on water and land resources and competition for food.

(1) Environmental impact—Biofuels require additional land and water resources. The Millennium Ecosystem Assessment finds that agriculture already is the largest factor in ecosystem modification (Alcamo *et al.*, 2005; MEA, 2005). With growing population and rising income, pressures on natural resources will intensify, leading to more loss of natural habitat. Further, water scarcity already is a limiting factor in food production in many regions (CA, 2007). Biofuel crops such as sugar are water intensive and often produced under monoculture, leading to increased water scarcity and water pollution. With increasing population, incomes and urbanization, water demand will rise and recent forecasts warn of impending global problems unless appropriate action is taken to improve water management and increase water use efficiency (Seckler *et al.*, 1998). Already 1.2 billion people in the global population live in areas where water is scarce even today (CA, 2007). To meet future global food demand by 2050, irrigation withdrawals may have to increase by another 20%, even under an optimistic productivity scenario (Fraiture *et al.*, 2007). Water for biofuels will add to pressure on water resources that already are stressed, or will soon be, in many places.

(2) Competition with food—There are also concerns that with increased demand for biofuel crops, competition for limited land and water resources will raise agricultural commodity prices. Rosegrant *et al.* (2006) foresee substantial price increases in cassava, sugar, oil crops and grains. Brown (2006) attributes recent corn price increases in the USA to increased demand owing to new biofuel plants. China lowered its ethanol targets after corn prices increased by 7% and other grain prices also increased allegedly because of increased demand from biofuel plants (China News, AFP, 2006). While higher food prices benefit landed farmers, they adversely affect the urban and landless poor. Pimentel (2003), among others, rejects the use of food crops for energy in a world where hunger

[6] The USA paid 2 billion dollars of subsidies to produce 16 billion liters of biofuel (Kammen, 2006). That is a subsidy of 0.13 dollars per liter.

persists on ethical grounds. On the other hand, current low – and by and large still declining – food prices point to a surplus production capacity, seemingly indicating that there is no direct competition between food and fuel, except possibly in the very short term.

3. Present land and water requirements

3.1. Land

At present we estimate the amount of land and water resources devoted to biofuel crop production to be 11–12 million ha, around 1% of the total area under crops (Table 1). In Brazil, the biggest bioethanol producer, 2.5 million ha (5% of the cropped land) is used for biofuel production, with a production rate of ethanol of 6,200 l ha^{-1}, mostly from sugarcane. The USA, the second biggest ethanol producer, allots nearly 4 million ha to biofuel crops (4% of the total cropped area), with yields of roughly 3,300 l ha^{-1}, mostly from maize. Using the data and conversion ratios listed in Table 1, we estimate that the global average ethanol production from 1 ha of land is around 3,500 l. This is consistent with estimates by International Energy Agency (IEA) (2004a). In Europe, where biodiesel is the main product made from rapeseed, 1 million ha is used, yielding on average 1,700 l ha^{-1} of biodiesel.

China is now becoming a major player in biofuel production, ranking among the world's top three ethanol producers. In 2002 it produced 3.6 billion liters of bioethanol in 2002 of which 76% was derived from maize (China News, AFP, 2006). At prevailing yields and conversion factors this corresponds to nearly 2 million ha of land, or only 1% of the total cultivated area in China. Production in India is roughly half that of China but also projected to grow rapidly. Present bioethanol production is 1.7 billion liters, derived predominantly from sugarcane. India, the world's second largest sugar producer, is now also actively promoting biodiesel from Jatropha, a tropical tree-based oil crop. Jatropha can produce up to 1500 l ha^{-1} biodiesel in the most favorable soil and water circumstances, though usually it produces much less (Mkoka & Shahanan, 2005). Because the trees can grow on marginal land with limited water and its seeds are non-edible, it does not compete directly with food (in terms of land and water resources). Together with sugarcane, Jatropha and other crops for biofuel production occupy only 0.3% of India's total cultivated area.

3.2. Water

Globally around 7130 km^3 of water is evapotranspirated by crops per year, without accounting for biofuel crops (Molden *et al.*, 2007a). Biofuel crops account for an additional 100 km^3 (or around 1%). In terms of irrigation water, the share is slightly higher because of the relatively large share of irrigated sugarcane in the biofuel mix (Table 1). Total irrigation withdrawals amount to 2,630 km^3 per year globally (Fraiture *et al.*, 2007) of which 44 km^3 (or 2%) is used for biofuel crops (Table 1). It takes on average roughly 2,500 l of crop evapotranspiration and 820 l of irrigation water withdrawn to produce one liter of biofuel. But regional variation is large. In Europe where rain-fed rapeseed is used, the amount of irrigation for biofuel crops is negligible. In the USA, where mainly rain-fed maize is used, only 3% of all irrigation withdrawals are devoted to biofuel crop production, corresponding to 400 l of irrigation water withdrawals per liter of ethanol. In Brazil where the main biofuel crop – sugarcane – is mostly

Table 1. Biofuels land and water use (2005).

Bioethanol	Bioethanol (million liters)*	Main feedstock crop	Feedstock used (million tonnes)†	Area biofuel crop (million ha)	% total cropped area used for biofuels‡	Crop water ET (km^3)§	% of total ET used for biofuel	Irrigation withdrawals for biofuel crops (km^3)	% of total irrigation withdrawals for biofuels‖
Brazil	15,098	Sugarcane	167.8	2.4	5.0	46.02	10.7	1.31	3.5
USA	12,907	Maize	33.1	3.8	3.5	22.39	4.0	5.44	2.7
Canada	231	Wheat	0.6	0.3	1.1	1.07	1.1	0.08	1.4
Germany	269	Wheat	0.7	0.1	1.1	0.36	1.2	–	0.0
France	829	Sugarbeet	11.1	0.2	1.2	0.90	1.8	–	0.0
Italy	151	Wheat	0.4	0.1	1.7	0.60	1.7	–	0.0
Spain	299	Wheat	0.8	0.3	2.2	1.31	2.3	–	0.0
Sweden	98	Wheat	0.3	0.0	1.3	0.34	1.6	–	0.0
UK	401	Sugarbeet	5.3	0.1	2.4	0.44	2.5	–	0.0
China	3,649	Maize	9.4	1.9	1.1	14.35	1.5	9.43	2.2
India	1,749	Sugarcane	19.4	0.3	0.2	5.33	0.5	6.48	1.2
Thailand	280	Sugarcane	3.1	0.0	0.3	1.39	0.8	1.55	1.9
Indonesia	167	Sugarcane	1.9	0.0	0.1	0.64	0.3	0.91	1.2
S. Africa	416	Sugarcane	4.6	0.1	1.1	0.94	2.8	1.08	9.8
World ethanol	36,800			10.0	0.8	98.0	1.4	30.6	2.0
Biodiesel	1,980			1.2		4.7			0.0
Ethanol plus diesel	38,780			11.2	0.9	102.7	1.4	0	1.1

* Dufey (2006).
† Conversion estimates from IEA (2004a, Table 3.1, page 53) and Dufey (2006), based on main crop used. The wide range in variation of both feedstock production efficiencies and conversion process efficiencies suggests that more work is needed in this area (IEA, 2004a).
‡ total cropped area estimated from WATERSIM model baseline year (see Fraiture, 2007 and Fraiture *et al.*, 2007).
§ Total ET estimated from WATERSIM model baseline year (Fraiture, 2007; Fraiture *et al.*, 2007).
‖ Total irrigation withdrawals estimated from WATERSIM baseline year (Fraiture, 2007; Fraiture *et al.*, 2007).

grown under rain-fed conditions, very little irrigation water is used for ethanol production. On the other hand China withdraws on average 2,400 l of irrigation water to produce the amount of maize needed for one liter of ethanol. Around 2% of total irrigation withdrawals in China are therefore for biofuel crop production. With high sugarcane yields and conversion efficiency, Brazil yields more than 6,200 l ha^{-1} bioethanol. In India where conversion efficiencies are lower, one hectare yields 4,000 l. As Indian sugarcane is fully irrigated, water withdrawals for every liter of ethanol are nearly 3,500 l.

4. Role of biofuels in future energy

4.1. Future energy and the role of biofuels

Future energy use depends on many factors, but the main are GDP growth and price of energy. Although both factors are very hard to predict, it is likely that China's and India's economies and thus oil demand, will continue to grow rapidly. The International Energy Agency foresees a growth in global oil demand of 60% from 4,500 billion liters per year in 2002 to 7,700 billion liters in 2030. China and India alone will be responsible for 68% of this increase (IEA, 2004b). Oil demand for transport is an important component of oil demand. In 2002 the OECD used 30% of its oil product supply for motor gasoline, and the USA more than 40%. In non-OECD countries where private car ownership is less common the share is smaller. For example, in China this percentage is 17% (IEA, 2005a). Globally, gasoline demand is now estimated at 1,200 billion liters per year (Dufey, 2006). We use those estimates combined with information about country policies and targets as a basis for our assessment of the potential impact of increased biofuel production on water use.

Table 2 provides an overview of assumptions on the future share of biofuels, consistent with the expectations of the International Energy Agency (IEA, 2004a) and Rosegrant *et al.* (2006). Under a scenario where biofuels are actively promoted by government support, the share of demand may reach 7.5% of total gasoline demand globally, equivalent to 140 billion liters by 2030; a near quadrupling relative to the base year.

4.2. Future biofuels in China

With oil consumption more than doubling, China's oil import dependence will increase dramatically from 34% now to 70% in 2030 (IEA, 2004b). Energy consumption in road transport is expected to grow by 5% annually over the coming decades, though projections vary by an order of magnitude depending on assumptions about GDP, car ownership, mileage and policy scenarios (Schipper & Ng, 2005). To curb oil dependency, air pollution and GHG emissions and support rural economies, China has set a goal of producing 6 million tonnes of cleaner-burning substitutes to coal and oil by 2010 and 15 million tonnes by 2020 (China News, AFP, 2006). In 2020 this is equivalent to 18 billion liters of gasoline energy equivalent, or 9% of projected gasoline demand.

Although recently the growth in ethanol production slowed down over fears of increased maize prices, in our biofuel scenario we assume a 9% share by 2030, which is consistent with Rosegrant *et al.* (2006), implying a five-fold increase over 2002.

Table 2. Gasoline and biofuels.

	Gasoline (billion liters/year)*			Biofuel contri bution % energy equivalent		Biofuels (billion liters)		
	2002	2030	Annual growth (%)	2005	2030	2005	2030	Annual growth (%)
USA, Canada	500	667	1.0	1	5	13.1	51.3	5.6
EU	131	150	0.5	2	10	3.8	23.0	7.5
China	50	128	3.4	3	9	3.6	17.7	6.5
India	24	54	2.9	3	10	1.7	8.3	6.4
Africa	23	59	3.4	1	2	0.4	1.8	6.0
Brazil	17	35	2.5	44†	65†	15.1‡	34.5	3.4
Indonesia	12	25	2.8	1	2	0.2	0.8	6.3
World	1164	1747	1.5	2.1	7.5	38.7	141.2§	5.3

* Based on IEA (2005b). Conversion factors see: http://bioenergy.ornl.gov/papers/misc/energy_conv.html
† Includes substantial exports of biofuels.
‡ Mainly South Africa.
§ Projections are in line with IEA (2004a) and Rosegrant *et al.* (2006).

4.3. Future biofuels in India

Oil demand in India is expected to grow by a factor 2.2 by 2030, increasing the oil import dependency from 69% now to 91%. With the number of vehicles doubling between 2002 and 2020 (IEA, 2004b), gasoline demand will make up a substantial part of this increase. The Indian Planning Commission has therefore proposed a program to produce ethanol to be blended with gasoline and biodiesel to be blended with high speed diesel. The ethanol is primarily derived from sugarcane and diesel from the tree-based oil crop Jathropa. The policy of 5% blending of gasoline with ethanol was made compulsory in 2003 in 9 states, but owing to high costs and red tape the measure was recently abandoned in most of them (Padma, 2005). The Planning Commission also intends to blend high speed diesel with 20% Jatropha-based biodiesel by 2012. The Indian government's Vision 2020 document states that cultivating 10 million ha with Jatropha would generate 7.5 million tonnes of fuel a year, creating year-round jobs for five million people. But despite ambitious programs, targets are likely to be missed owing to the high costs of Jatropha-based fuel and red tape (Padma, 2005). In our biofuel scenario we assume that 10% of the gasoline demand in 2030 will be met by sugar-based bioethanol (in energy equivalents), requiring 9 billion liters, an increase by a factor 4.7 compared to 2002. This is in line with estimates by IEA (2004a) and Rosegrant *et al.* (2006). The role of Jatropha is likely to remain small until major technology breakthroughs are realized. In addition, Jatropha production does not generally compete with food crops for land and water, in particular irrigation water.

5. Implications for land and water

What are the implications for land and water resources of quadrupling biofuel production? To what degree will this compete with food crops for land and water resources? To address these questions we compare actual and projected land and water use for food production with and without additional demand for biofuels. As a baseline to simulate water and food demand for agriculture without biofuels, we use the optimistic scenario developed for the Comprehensive Assessment of Agricultural Water Management (Fraiture *et al.*, 2007). This scenario is quantified using the WATERSIM model (Fraiture, 2007), a model that has been developed and tested as part of the comprehensive assessment. The optimistic scenario assumes a combination of strategies to meet food demand while minimizing additional water requirements. Those strategies include improving rain-fed agriculture through better rainwater management, improving yields and water productivity in existing irrigated areas and expanding irrigated areas and trade, according to regional strengths and limitations. One of the conclusions of the Comprehensive Assessment of Agricultural Water Management is that water resources are sufficient to meet food security, poverty reduction and environmental goals simultaneously, provided the right policy and investment measures are taken (CA, 2007). However, energy crops were not included in the analysis.

5.1. Food, biofuels, land and water

Our baseline scenario foresees that by the 2030, global maize supply will reach 890 million tonnes to meet food and feed demand, an increase of 40% compared to 2005. Most of this increase stems from greater feed needs to meet increased meat demand, a result of higher incomes. Sugar production will rise to 2,460 million tonnes of cane, up by 35% from the base year, again mainly due to dietary changes stemming from income growth. Assuming no changes in feedstock[7] and conversion efficiency, biofuels will require around 180 million tonnes of maize, 525 tonnes of raw sugarcane and 50 tonnes of oil crops. These amounts are 20%, 25% and 80%, respectively, above baseline scenario production (Table 3).

On a global level the biofuel scenario requires 30 million additional hectares of cropped area (compared to 1,400 million ha for food crops), 170 km^3 additional evapotranspiration (ET) (compared to 7,600 km^3 for food) and 180 km^3 more withdrawals for irrigation (compared to 2,980 km^3 for food) (Table 4). While for individual crops increases may be substantial, compared to the sum of all crops, increases are modest. These figures amount to increases in resource use of only 2–5%, levels too small to lead to major changes in agricultural systems at a global level.

But on country level a different picture emerges. China needs to produce 26% more maize and India 16% more sugarcane above the base scenario levels. This means 35.1 km^3 and 29.7 km^3 of additional irrigation water in China and India, respectively, while both countries already face regional and seasonal water shortages.

5.2. China's water and scope for further development (or the lack thereof)

Irrigation plays a dominant role in China's food production. An estimated 75% of total grain production, 90% of vegetables and 80% of cotton comes from irrigated areas. About 70% of total wheat and 60% of total maize are harvested in the northern region (i.e. the Yellow, Huaihe and Haihe river basins), where more than 60% of the area is irrigated and groundwater resources are already extensively

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[7] Feedstock is the crop or biomass type used to derive biofuel.

Table 3. Food and feedstock.

Crop	Global production for food and feed 2030 (million tonnes)*	Need to meet biofuels demand (million tones)	% increase to meet biofuel demand
Maize	890	177	20
Sugarcane	2,136	525	25
Rapeseed	64	51	80

* CA scenario using WATERSIM model (see Fraiture, 2007 and Fraiture *et al.*, 2007).

overexploited (Liao, 2005). The south imports food from the water stressed northern region and the international food market (Zhou & Tian, 2005). Earlier the water-rich south produced a surplus that was exported to the northern provinces. But with economic development and associated higher opportunity costs for land and labor, agricultural production in the developed south is becoming less attractive to farmers who have more opportunities to work in non-agricultural sectors (Liao *et al.*, 2007).

The total volume of water resources in China ranks sixth worldwide, but per capita supplies are only 2200 m^3 in 2000, about one-quarter of the world average. Particularly, in the north – Haihe, Huaihe and Yellow river basins – per capita water resources are low, only 290 m^3, 478 m^3 and 633 m^3, respectively and declining groundwater tables caused by overdraft are common. Frequent droughts, floods and water logging hazards result in unstable agricultural production and a serious imbalance between water supply and demand (Liu & Zhikai, 2001; Liao *et al.*, 2007). A major water transfer project from south to north currently under implementation will alleviate some of the water shortage problems, but most of the transferred water will be used in the domestic and industrial sector rather than agriculture.

Because of water limitations in the north and land constraints and high opportunity costs to labor in the south, our base scenario foresees limited scope for further improvements in production. The scenario puts a limit on land and water use to prevent further environmental degradation. Maize demand in China will increase substantially to 195 million tonnes in 2030 (up by 70% from 2000), mainly because of growth in per capita meat consumption as a result of income growth. Part of the additional demand can be met through productivity growth and slight area increase, but even under optimistic yield growth assumptions imports must increase to 20 million tonnes from 2 million tons in 2004. Under such a scenario it is quite unlikely that the additional maize demand for biofuel can be met without further degrading water resources or major shifts in cropping pattern at the expense of other crops. More likely, under an aggressive biofuel program, China will have to import more maize (or the crop displaced by maize), which will undermine one of its primary objectives, that is, curbing import dependency.

5.3. Agricultural water use in India

Irrigation plays a major role in India's food supply. At present some 63% of cereal production originates from irrigated areas. Wheat and rice are mostly produced under irrigated conditions, while maize and other grains are grown in rain-fed areas. Close to 85% of the area under sugarcane – the crop currently most used in bioethanol – is irrigated. It is estimated that the total harvested area amounts to

Table 4. Biofuels land and water, projections for 2030.

	Biofuel (billion liters)	Main feedstock crop	Feedstock (million tons)	National production for food and feed, 2030*	Additional production for biofuels (%)	Area for biofuel crops (million ha)	% of total cropped area for biofuels†	Crop ET for biofuels (km^3)	% total crop ET for biofuels‡	Irrigation withdrawals for biofuel crops (km^3)	% of total irrigation withdrawals for biofuels§
USA, Canada	51.3	Maize	131	316	42	14.1	9	76.0	11	36.8	20
EU	23.0	Rapeseed	51	21	242	14.6	28	30.1	17	0.5	1
China	17.7	Maize	45	175	26	7.8	4	43.6	4	35.1	7
India	9.1	Sugarcane	101	613	16	1.1	1	21.6	3	29.1	5
S. Africa	1.8	Sugarcane	20	29	70	0.2		3.9	12	5.1	30
Brazil	34.5	Sugarcane	384	513	75	4.4	7	86.3	14	2.5	8
Indonesia	0.8	Sugarcane	9	41	21	0.1	0	2.5	1	3.9	7
World	141.2					42.2	3	261.5	3	128.4	4

* Total food–feed demand estimated from WATERSIM model CA scenario (see Fraiture, 2007 and Fraiture *et al.*, 2007).
† Total cropped area is estimated from WATERSIM model CA scenario (see Fraiture, 2007 and Fraiture *et al.*, 2007).
‡ Total ET is estimated from WATERSIM model CA scenario (see Fraiture, 2007 and Fraiture *et al.*, 2007).
§ Total irrigation withdrawals is estimated from WATERSIM CA scenario (see Fraiture, 2007 and Fraiture *et al.*, 2007).

175 million ha (in 2005) of which roughly 45% is irrigated. More than half of the irrigated area is under groundwater irrigation, mostly privately owned tube wells.

Total renewable water resources are estimated at 1,887 km^3, but only half (or 975 km^3) is potentially utilizable. Total water resources amount to 2,025 m^3 per capita (for the year 2000), or only around 1,100 m^3 of potentially utilizable per capita supplies (Amarasinghe *et al.*, 2005). Water withdrawals in India were estimated at 630 km^3 in the year 2000, of which more than 90% was for irrigation. Spatial variation is enormous. The river basins of the Indus, Pennar, Luni and westerly flowing rivers in Kutsch and Gujarat are absolutely water scarce and much of North India suffers from groundwater overdraft (Amarasinghe *et al.*, 2005). To address water scarcity, the government of India is exploring the possible implementation of a series of large scale interbasin transfers to bring water from water abundant to water short areas. This so-called "Linking of Rivers" project is controversial, because it is expensive; it will have adverse impacts on biodiversity and freshwater ecosystems and will cause the displacement of millions of people. Although parts are under development now, it is unlikely that this project will be fully implemented and operational in the near future. Our base scenario therefore foresees relatively limited scope for further irrigation development. The scenario adopts optimistic assumptions to improve productivity in both irrigated and rain-fed agriculture.

Cereal and vegetable demand in India is projected to increase by 60% and 110%, respectively from 2000 to 2030. The irrigated harvested area is expected to increase slightly from 75 to 84 million ha. A major part of these increases will be met through improvements in yields although small increases in imports are inevitable. Sugarcane production increases from 300 to 605 million tonnes for food purposes. Our biofuels scenario implies that an additional 100 million tonnes of sugarcane is needed for the production of bioethanol, for which 30 km^3 additional irrigation water needs to be withdrawn. This amount will be likely to come at the expense of the environment or other irrigated crops (cereals and vegetables), which will then need to be imported. For many years, the Indian government has focused on achieving national food self-sufficiency in staples. More recently, as the imminent danger of famines has decreased and non-agricultural sectors have expanded, the national perspective regarding production and trade has changed. But it is unclear if India would choose to import food to free up necessary resources to grow biofuel crops.

6. Summary and discussion

Biofuels are promoted for energy security, economic, political and environmental reasons. At present the role of biofuels in energy supply and its implications for water and land use are limited. But there are plans and policies in place around the world to increase biofuel production. If all national policies and plans for biofuels are successfully implemented, 30 million additional hectares of crop land will be needed along with 180 km^3 of additional irrigation water withdrawals. Although globally this is less than a few percentage points of the total area and water use, the impact for some individual countries could be highly significant, including China and India, with significant implications for water resources, and with feedback into global grain markets. In fact it is unlikely that fast growing economies such as China and India will be able to meet future food, feed and biofuel demand without substantially aggravating already existing water scarcity problems, or importing grain, an outcome which counters some of the primary reasons for producing biofuels in the first place.

This analysis assumes no major changes in feedstock. Yet, this may become an important factor in the biofuel discussion. From a water perspective it makes a large difference whether biofuel is derived from fully irrigated sugarcane grown in semi-arid areas or rain-fed maize grown in water-abundant regions. The use of water-extensive oil seeds (such as Jatropha trees), bushes, wood chips and crop residuals (i.e. straw, leaves and woody biomass) is promising in this respect, although a few caveats are necessary. With existing technologies, biofuel yields from Jatropha trees are fairly low (1,500 l ha^{-1} biodiesel at most) and processing is relatively expensive. Crop residuals, grass and tree leaves often are used as animal feed or organic fertilizer (compost), particularly in India where more than 90% of the energy intake comes from grass and crop residual (Kemp-Benedict, 2006) and feed supplies are already short (Reddy *et al.*, 2003). Furthermore, the technology to convert woody biomass into biofuels (i.e. the use of enzymes to ferment straw into lignocellulosic bioethanol) is in development and not commercial yet (Heywood, 2006).

Our analysis implicitly assumed that biofuels will become a cost effective alternative to fossil fuels, because conversion technology will become more efficient while the crude oil price remains high. This may not be the case. Rather than shortage of proven crude oil supply, high oil prices are caused by political instability and bottlenecks in refinement capacity. These human-induced factors may change, causing the oil price to drop again to levels where biofuels are economically unfeasible. This makes investments in biofuel plants risky without subsidies or guaranteed markets through regulations.

In this paper we did not address trade issues related to biofuels. The analysis will change considerably if India and China import biofuels (or food) rather than cultivate energy crops domestically.

Will an increase in biofuel demand lead to sustained higher food prices and adversely affect poor consumers in developing countries? There is some evidence that it might. Brown (2006) relates recent increases in corn prices to the opening of new biofuel plants. Rosegrant *et al.* (2006) foresee substantial increases in food prices in an aggressive biofuel scenario. On the other hand, maize demand for feed more than doubled from 150 million tonnes in 1961 to 410 million tonnes in 2002 while the long-term trends in the world market price continued to decline. At a global level additional demand for agricultural commodities is small in comparison to projected food and feed demand. While some areas may face water and land limitations, others have sufficient spare capacity, provided that productivity improvements materialize (Molden *et al.*, 2007b). Thus, production may take place in land and water abundant regions that are currently not involved in producing biofuels. What the impact will be on food prices are impacted will critically depend on trade barriers, subsidies, policies and limitations to marketing infrastructure, maybe more so than a lack of physical capacity.

Is it ethical to use food crops to produce energy, in a world where there are still 860 million people undernourished? Some authors voiced strong opinions against biofuels, arguing that when poor consumers are pitched against rich car owners, the poor will loose out (Pimentel, 2003; Brown, 2006). But this statement needs nuance. Malnourishment occurs because of lack of access to food rather than global food shortage. Further, the most commonly used biofuel crops are sugar crops and maize. Sugar is a cash crop (not a staple) and may provide additional income to poor farmers; although this is a challenge in itself as such opportunities are usually captured by the better off farmers. Maize is primarily used to feed animals to produce meat and milk. Globally 65% of all maize is used to feed animals; in the USA it reaches 75%. With rising living standards and urbanization, meat consumption will continue to increase (it more than tripled in China over the past decades, so far without a notable impact on price). So, the "unfolding global conflict over food" – as eloquently coined by Brown (2006) – may not be between cars and the poor as he envisions, but rather between cars and carnivores.

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