Biofuels and Water: an exploration

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Introduction

The biofuel hype has lead to debates on its environmental performance, economic feasibility and social desirability. Relatively little attention has been given to the effect of energy crop production on water demand, Berndes[1] and De Fraiture[2] being the exception to the rule. This paper will analyse the different impacts that biofuel production will have on water use and availability. We will first introduce biofuels and describe what the main drivers are behind the growth of biofuel production.

Biofuels include ethanol, biodiesel, methanol, and P-series fuels[3]. This despite of the fact that the process of photosynthesis that turns the energy of the sun into biomass is not very efficient; it has often low energy gain ratios and requires huge amounts of land and water. Second generation cellulosic technologies that derive energy from crop residues have the clear potential to augment biofuel production, but these technologies are probably 10-20 years away from commercial reality.

High oil prices have caused an impetus for the production of biofuel in recent years. They are caused by human induced factors like political instability and bottlenecks in refinement capacity, rather than by shortage of proven crude oil supply. These human induced factors may change, causing the oil price to drop to low levels where biofuels are not competitive to fossil fuels[4]. The oil price per barrel at which biofuels currently become competitive varies from $25-30 in Brazil, $50-60 in the US, and $70 in Europe, because of widely varying resource endowments and factor costs. Brazil has for instance ample land and water and can produce against low costs. Currently the production of biofuels is based in Brazil, US, China and India, and Europe (see Figure 1).

Figure 1: Top Five Biofuel Producers in 2005

Ethanol			Biodiesel		
Country	Million litres	Feedstocks	Country	Million litres	Feedstocks
Brazil	16,509	Sugarcane	Germany	1,922	Rapeseed
US	16,236	Corn	France	512	Soybean
China	2,001	Corn, wheat	US	292	Rapeseed
EC	951	Sugarbeet, wheat, sorghum	Italy	227	Rapeseed
India	299	Sugarcane	Austria	83	Rapeseed

(Source: Davis, 2007)

Other areas with a suitable agro-climate include Sub-Saharan Africa (provided water is either available from rainfall or irrigation) and Latin America. Elsewhere the rationale for developing biofuels is either to contribute to climate control (in Europe) or, (e.g. in India) to increase rural employment and incomes, based on wasteland and oil-producing crops (Jatropha and Pongania). Sweet sorghum may provide a combination of grain production plus the potential to produce biofuels, although it may displace food crops from the rainfed areas.

Main drivers of biofuel production

As was indicated in the introduction, there are a number of reasons why governments are promoting biofuels even when subsidies are needed for them to be commercially viable. These include[5]:

1. Energy security: reduce dependence on imported petroleum
2. Climate change (decrease greenhouse gas–GHG emissions)
3. Concerns about trade balances
4. Rural development and poverty reduction

Some are more important for developed countries (such as energy security or reduction of GHG) and others are more important for developing countries (such as concerns about trade balances or rural development).

Reduce dependence on imported petroleum (US)

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[6].

The US for instance has supported the production and use of ethanol from corn and sugarcane for these reasons. US support has included exemption from federal gasoline excise taxes, whole or partial exemption from road use (sales) taxes in nine states, a federal production tax credit, and a federal blender's credit[7]. US federal subsidies for ethanol refiners amount to 51 cents a gallon. The subsidies have helped create a boom in ethanol production and have made ethanol more profitable than ever.

Climate change

In the 1990s, The International Panel on Climate Change distinguished three main options for the mitigation of atmospheric CO2 concentrations by the agricultural sector: (1) reduction of agriculture-related emissions
(2) creation and strengthening of C sinks in the soil
(3) production of biofuels to replace fossil fuels

Energy crops or biofuels have a considerable potential for mitigation of atmospheric CO_2 concentrations by counteracting the use of fossil fuels. Biofuel production on 10–15% of the land currently in agricultural use or in agricultural set-asides could substitute for 0.3–1.3 Pg C $year^{-1}$ of fossil fuel, while recovery and conversion of crop residues could substitute for an additional 0.1–0.2 Pg C $year^{-1}$ of fossil fuel[8].

Concerns about trade balances

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. In Brazil, for instance, it has been calculated that the replacement of gasoline by bioethanol saved some US$ 43.5 billion between 1976 and 2000 (US$ 1.8 billion/year)[9]. But also for small countries, it may be an interesting option. Jamaica for instance imports 90% of all its oil products, and high prices are pushing the island's trade balance into the red. Producing biodiesel from castor beans has become an economically attractive alternative. Castor beans have a high oil content and are widely grown by smallholders on the island. The poisonous plant provides a safe opportunity for biodiesel development without the risk of displacing food crops. It requires relatively few inputs and thrives in poor soils[10].

Rural development and poverty reduction

A potential benefit associated with biofuels is their positive impact on agricultural employment and livelihoods. Growing biofuel crops such as sugarcane in developing countries can employ many small farmers or (landless) poor workers in rural areas, thus having a positive effect on rural development.

Secondly, the substitution of foodcrops for biofuel crops may lead to higher prices for farmers. This has already happened in Mexico where higher food prices led to the “tortilla wars”. Although higher food prices will negatively affect the (poor urban) consumers, it will benefit (poor rural) producers.

Global implications of biofuel production on water use

Water is often not mentioned in most biofuel production scenarios. However, increased biofuel production may have severe implications for global water use. These implications can be distinguished in four areas:

1. Increased demand for irrigation water
2. Increased demand for water in ethanol processing factories
3. Pollution of groundwater through increased used of pesticides
4. Destruction of natural forests and related disrupted water functions
5. Possible impact of future (second generation) biofuel technologies

Increased demand for irrigation water

Biomass production for energy will compete with food crops for scarce land and water resources, already a major constraint to agricultural production in many parts of the world. A study by IWMI has calculated that there be relatively minor impacts of increased biofuel production on the global food system and water use. Current biofuel production utilizes about 1% of crop water use. This will increase to about 3% in 2030. However, local and regional impacts could be substantial. In particular in China and India where the strain on water resources will be such that it is to be expected that policy makers will not pursue biofuel options, at least those based on traditional field crops[11].

The impact of biofuels on water use has not been explicitly quantified in the Comprehensive Assessment of water management in agriculture[12]. Pursuing biofuel production in water-short areas will put pressure on an already stressed resource, especially if it requires additional water (irrigation or rainfall). The water consumed in the production of biofuel varies by crop and location. From a water perspective it makes a large difference whether biofuel is produced by fully irrigated or rainfed crops. Sugarcane in Brazil evaporates 2200 litres for every litre of ethanol, but this demand is met by abundant rainfall. In arid areas, irrigation must make up the shortfall. In India, for example, a litre of sugarcane ethanol requires 2500 litres of water[13]. Almost all of India's sugarcane –potentially the country's major ethanol crop– is irrigated, as is 45% of China's likely main biofuel crop, maize.

Growing sugarcane to produce the 9 billion litres of bio-ethanol needed to meet 10% of India's petrol demand by 2030 will increase current demand for irrigation water by 3.4% which is equivalent to 22,000 billion litres. Growing maize to produce enough ethanol to meet 9% of China's predicted demand for gasoline by 2030 will increase current demand for irrigation water by 5% or 26,000 billion litres[14].

Berndes[15] uses the IIASA/WEC scenarios[16] to calculate addition water requirements assuming that 15% of the energy crop evapotranspiration is provided by means of irrigation. If the average efficiency in irrigation water supply is 50 percent, then up to 370 km^3 (or 370,000 billion litres) of additional water would have to be withdrawn in 2025. In year 2100, up to 2281km^3 (or 2,281,000 billion litres) of additional water would have to be withdrawn. It is clear that such additional withdrawals would lead to substantial increases in total withdrawals of irrigation water.

However, the study also determined that the impact will be very different for different countries, depending, amongst others, on the availability of (rain)water and whether. It concludes that[17]:

- Water availability appears not to impose a constraint on the assumed level of bioenergy production in countries such as Canada, Brazil, Russia, Indonesia and in several countries in sub-Saharan Africa[18].
- Several countries (e.g., South Africa, Poland, Turkey, China, and India) are already facing a scarce water situation, which is projected to become increasingly difficult even if large-scale bioenergy feedstock production would not materialize.
- Other countries, such as USA and Argentina, are projected to join the group of countries that withdraw more than 25 percent of available water. The reason is large per-capita withdrawals rather than scarce availability. Argentina is assumed to produce as much bioenergy as Latin America as a whole on a per capita basis and USA is also expected to expand its production.

Increased demand for water in ethanol processing factories

Maize-based biofuel has disadvantages that are often not mentioned in studies evaluating the environmental effects[19]. Among them is the higher water consumption required by ethanol processing factories. A recent Economist article ("Ethanol and water: don't mix")[20] puts forward that shortage of processing water could be the Achilles heel of corn-based and perhaps cellulose-based ethanol[21]. By the end of 2008, the demand from new ethanol plants in the US would require a 254 percent increase in the volume of water used by the industry over the previous decade[22]. The production of ethanol in a modern ethanol plant uses about 3 litres of water to produce a litre of ethanol[23]. That was an improvement on 4 litres a year ago, but current technology is unlikely to improve much beyond that. In contrast, gasoline compares favourably to ethanol with only about 0.5 litres of water required per litre of gasoline[24].

Pollution of groundwater through increased use of fertilisers and pesticides

Few studies provide results on the negative environmental effects of biofuel production such as (ground)water pollution. However, biofuel crops such as sugar beets, corn and wheat use a significant amount of pesticides. In a simulation of the effect of various economic scenarios on groundwater pollution on French and German regions, and using a combination of economic, technical and hydrogeological modelling, Graveline *et al.* [25] find that the extension of biofuels is actually the worst case among their scenarios regarding nitrate pollution of groundwater.

A study by the American National Academy of Sciences[26] questions ethanol's environmental benefits, noting that despite the 12 percent reduction in greenhouse gases, ethanol has "greater environmental and human health impacts because of increased release of five air pollutants and nitrate, nitrite and pesticides." Both maize and soybean production have negative environmental impacts through movement of agrichemicals, especially nitrogen (N), phosphorus (P), and pesticides from farms to other habitats and aquifers.

Expansion of the agricultural frontier

The increased profitability of biofuel crops may lead to the expansion of the agricultural frontier. But the demand for biofuels has also resulted in a global rise in *agricultural* commodity prices, which may create an additional impetus to expand the agricultural frontier. The increasing pressure to expand the agricultural frontier will have various effects on water use. First, it will likely expand the use of water for irrigation, except in areas where agricultural crops can be produced with rainwater. Second, it will, in many cases, lead to the conversion of natural areas into agricultural areas. For instance, forests have already been cleared for palm oil production in countries such as Indonesia and Malaysia. And if the increased demand for biofuel were met by expansion of soy production, this would imply further environmental pressure in the sensitive drier savannah areas of north-central Brazil (the cerrado) and in the Amazon forests[27]. Natural areas such as forests often provide various environmental services related to water, such as watershed protection. A switch to agricultural crops may jeopardise these functions. For instance, palm oil plantations may not be able to provide similar water-related services as natural forests.

In the case where an expansion into natural areas is avoided by intensifying production on existing agricultural land, there may still be an effect on water use. First, intensifying production may require (more) irrigation water. Second, an increase in inputs such as fertiliser and pesticides which is necessary to increase productivity, may lead to increase (ground)water pollution. The Comprehensive Assessment of Water Management in Agriculture or CA[28] estimates that with today's food production and environmental trends, if continued, there will be water crises in many parts of the world. Already the competition for scarce water resources in many places is intense. These crises will only be intensified with rising agricultural prices, which the CA did not take into account.

Possible impact of future (second generation) biofuel technologies

The above analysis is based in the first generation biofuel technologies. However, the current bioenergy-triggered boom could be followed by a marked bust cycle, caused when a second generation technologies based on forest products (cellulose) become feasible and profitable. This shift could make not only first-generation traditional agricultural and food commodities production unprofitable, but the entire production chain as well, because second-generation processing technologies will be entirely different. For food prices, this should result in less demand and possibly a return to falling real prices[29]. This may lead to the use of natural forests to provide the material for cellulose, potentially threatening the existence of large forest areas such as the Amazon. As described above, this may have various implications for water, as forests play a crucial role in watershed protection. However, trees are net users of water. Setting up plantations with (fast-growing) tree species to provide the material for second-generation biofuel may have huge implication for (ground)water use. It may also lead to a shift in the location of biofuel production, e.g. to countries where forestry is a dominant land use (e.g. Scandinavia).

On groundwater pollution, second generation biofuels have different impact, depending on which crop is used. Perlack *et al*[30]*.* report for instance, that displacing annual crops with perennial grassy crops, considered as a second generation feedstock, could reduce pesticide and net fertilizer use. But other crops may have negative impacts[31]. Water pollution can be caused by untreated oil palm mill effluent that contains chemicals[32]. The conversion of biomass to fluid fuels consumes little water compared to the evapotranspiration losses in energy crops production. However the effluent production from fermentation processes to produce ethanol may be substantial[33]. Therefore, in addition to water pollution linked to agriculture, further concerns about water pollution and consequent biodiversity loss can arise if water used in the processing technologies is not treated properly before returning to the environment.

Conclusions

Many studies on the environmental impact of biofuel production have focused mainly on the effect of a reduction of GHG emissions. There are only very few studies that have focused on the effect on other natural resources such as water. Although there is still a lack of quantitative date, what does seem to be quite clear, is that the development of biofuels will have a substantial impact on water use and availability, especially on a regional and local scale. As the pace and the extent to which biofuels will be developed depends to a large extent on energy prices, these will thus influence future water availability as well.

We have analysed the different impacts that the development of biofuels will have on water use and availability. The impacts are varied and sometimes indirect. First of all, an increased demand for irrigation water to grow biofuel crops will lead to an accelerated depletion of groundwater aquifers. Secondly an increased demand for water in ethanol processing factories will have a negative effect on water availability, which is already felt in some states of the USA. But it is not just water extraction (for the production of crops and processing of biofuel), but also the pollution of groundwater through increased used of fertilisers and pesticides that will impact the quality of groundwater.

More indirect effects are the expansion of the agricultural frontier to grow biofuel crops that is likely to occur when prices of biofuel crops continue to rise. The destruction of natural areas will have various environmental impacts, including the loss of watershed protection that is provided by natural forests.

Possible future impacts of second generation biofuel technologies are less certain, as they depend on the development of those technologies. It is expected that future biofuels are made from cellulose from trees. Depending on whether natural forests are used for this, or plantation forests different impacts on water can be expected.

References

Adams, D. and J. Zink. (2007). "Ethanol Faces Big Hurdle: Water Use the Plants Consume Hundreds of Thousands of Gallons of Water Daily. " *St Peterburg Times*.

Alternative Fuels Data Center. (2007). http://www.eere.energy.gov/afdc/ accessed 14 June 2007

Berndes, G. (2002). "Bioenergy and Water - the Implications of Large-Scale Bioenergy Production for Water Use and Supply", *Global Environmental Change*, 12(-): 253-271.

BioPact. (2007). "Jamaica Selects Castor Beans as Biodiesel Feedstock ". http://biopact.com/2007/08/jamaica-selects-castor-beans-as.html Access date: 23-08-2007.

CBD. (2007). "Biofuel Electronic Forum". http://www.cbd.int/forums/biofuel/impacts.shtml Access date: 23-08-2007.

Cole, V. (1996). "Agricultural Options for Mitigation of Greenhouse Gas Emissions", in *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*. W. R.T., Z. M.C. and M. R.H. eds. Cambridge: Cambridge University Press, pp. 747–771.

Comprehensive Assessment of Water Management in Agriculture. (2007). *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London/Colombo: Earthscan/International Water Management Institute.

Davis, C. (2007). "March 2007 Monthly Update: Global Biofuel Trends", *EarthTrends*. WRI.

de Fraiture, C., M. Giordano, and L. Yongsong. (2007). "Biofuels: Implications for Agricultural Water Use", Colombo, Sri Lanka: International Water Management Institute.

Dufey, A. (2007). "International Trade in Biofuels: Good for Development? And Good for Environment? " London: IIED, IIED Briefing.

European Commission. (2006). "An Eu Strategy for Biofuels: Impact Assessment", Brussels, Belgium: Commission of the European Community.

Graveline, N., M. Casper, J. Grimm-Strele, R. Koller, H. Lambrecht, J.-D. Rinaudo, and P. Van Dijk. (2006). "Integrated Modelling of Nitrate Contamination of a Large Scale Aquifer: Economical Modelling and Scenario Development". Paper presented at the International symposium Aquifers Systems Management, Dijon, France, 30 may-1th june 2006.

Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. (2006). "From the Cover: Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels", *PNAS*, 103(30): 11206-11210.

Keeney, D. and M. Muller. (2006). "Water Use by Ethanol Plants Potential Challenges", Minneapolis, Minnesota: Institute for Agriculture and Trade Policy. 7 pages.

Perlack, R.D., J.W. Ranney, and L.L. Wright. (1992). "Environmental Emissions and Socioeconomic Considerations in the Production, Storage, and Transportation of Biomass Energy Feedstocks", Oak Ridge, USA: Prepared for the U.S. Department of Energy. Oak Ridge National Laboratory.

Schmidhuber, J. (2007). "Impact of an Increased Biomass Use on Agricultural Markets, Prices and Food Security: A Longer-Term Perspective", Paris and Rome: Notre Europe and Food and Agriculture Organisation, Discussion paper. 34 pages.

Solomon, B.D., J.R. Barnes, and K.E. Halvorsen. (2007). "Grain and Cellulosic Ethanol: History, Economics, and Energy Policy", *Biomass and Bioenergy*, 31(6): 416-425.

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[1] (2002)
[2] (2007)
[3] (Alternative Fuels Data Center, 2007)
[4] (de Fraiture *et al.*, 2007)
[5] (Dufey, 2007; de Fraiture *et al.*, 2007)
[6] (Dufey, 2007)
[7] (Solomon *et al.*, 2007)
[8] (Cole, 1996)
[9] (Dufey, 2007)
[10] (BioPact, 2007)
[11] (de Fraiture *et al.*, 2007)
[12] (Comprehensive Assessment of Water Management in Agriculture, 2007)
[13] Crops need water for evapotranspiration and this is likely to be higher in India than in Brazil, which explains the difference of 300 litres.
[14] (de Fraiture *et al.*, 2007)
[15] (2002)
[16] The six scenarios represent very different evolutions of energy demand and supply patterns over the 21st century, and thus span over a wide range of possible futures. The global biomass supply for production of commercial energy carriers (such as electricity, hydrogen and alcohols) grows in all scenarios, but at quite different rates: it ranges from 47 to 123 EJ yr^{-1} in 2050 and from 157 to 304 EJ yr^{-1} in 2100 (Berndes, 2002)
[17] (Berndes, 2002)
[18] The fact that SSA countries are in this category is probably because no additional irrigation was assumed and biofuel crop production is based on rainfed agriculture.
[19] (e.g. Hill *et al.*, 2006)
[20] The Economist, Feb 28th 2008.
[21] (Keeney and Muller, 2006)
[22] There are 120 ethanol factory plants in the United States with another 77 under construction, mostly in the Midwest (Adams and Zink, 2007)
[23] (Paul Greene cited in Adams and Zink, 2007)
[24] It must be noted however, that the water needed in processing the crop is very little – in fact almost negligible – when compared with the water needed for producing the crop. However, processing water does add pressure to scarce water resources.
[25] (2006)
[26] (Hill et al., 2006)
[27] (Dufey, 2007)
[28] (2007)
[29] (Schmidhuber, 2007)
[30] (1992)
[31] (CBD, 2007)
[32] (European Commission, 2006)
[33] (Berndes, 2002)