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COMMENT

How the emergence of biofuels challenges environmental conservation

Both the largest resource consumption and the largest environmental harm are coupled to the supply of fossil energy to society and its related processes of energy and material conversion. 'Decarbonizing' energy supply by smart energy use and 'clean' energy technologies is therefore an important political goal, and one very prominent source of presumably 'clean' energy is constituted by biofuels. Worldwide agriculture is currently experiencing a paradigmatic shift from food to energy crop production. For example, 17% of Germany's croplands were used for biofuel production in 2007, and annual growth rates of energy-crop area have been around 30% (FNR [Fachagentur Nachwachsende Rohstoffe] 2007). What are the challenges of domestic biofuel production for nature conservation in the European Union (EU), one of the leading producers and consumers of biofuels? We highlight considerable impacts both on conservation lands and on nature conservation in agricultural and forest landscapes. We argue that the basic challenge for conservation is not biofuel use *per se*, but the way in which biomass is produced. Innovative land-use systems specifically designed for energy crops that have both a high energy productivity per area and support high structural and species diversity might offer a way out of this energy dilemma.

Unlike wind power, the use of biofuels implies not a single identifiable 'point source' of environmental impact, but rather a greater proportion of the terrestrial biosphere devoted to biofuel supply. For example, to substitute 6% of petroleum consumption in the USA would require the country's complete corn crop as input (Pimentel & Patzek 2006). Biofuels may be the renewable energy carrier with the highest relevance for biological conservation, but both conservation science and policy are just starting to understand the dimensions of the challenge.

The extent to which biofuels can replace fossil fuels and mitigate greenhouse gas (GHG) emissions varies strongly between different biofuel production paths. Life-cycle assessments for biofuels are complex and highly controversial; the system limits in terms of included environmental parameters and steps of the production process are rarely standardized, and assessments can hardly keep pace with the rapid developments in the field. Most assessments indicate that current forms of bioethanol and biodiesel production have low or even negative net energy outputs (see Pimentel & Patzek 2005). Moreover, significant GHG emissions (especially N_2O) can be released in consequence of nitrogen fertilizer inputs (Crutzen *et al.* 2007). Life-cycle assessments of different cropping systems can greatly clarify, for example mixtures of native grassland ('low input, high diversity') provided substantially more usable energy, greater GHG reductions and less agrichemical pollution per hectare than both corn-grain ethanol or soybean biodiesel (Tilman *et al.* 2006). Specifically, the ratio of energy output per energy input (necessary in farming and conversion processes) was 5.44 in the case of ethanol from mixed grassland biomass compared to 1.25 for corn-grain ethanol. This supported previous studies that found native switchgrass to be 15 times more energy efficient and 30 times more efficient in GHG reduction than corn (McLaughlin & Walsh 1998). Considering the choice of energy conversion, life-cycle assessments indicate that using biofuels for heat and electricity generation is generally superior to automotive fuels in terms of energy efficiency and GHG mitigation costs (German Advisory Council on the Environment 2007).

A central conflict in expanding biofuel production in agriculture and forestry consists of interactions with other land uses and especially with nature conservation (Plieninger *et al.* 2006). These vary in regard to 'first generation' and 'second generation' scenarios of biomass use (see later). They also affect the two basic nature conservation strategies of 'reserve conservation' and 'off-reserve conservation' (namely implementation of conservation on farmland and in managed forests) in different ways.

'First generation' biofuels (such as grain ethanol or rapeseed-based biodiesel) are overwhelmingly produced in the form of energy crops. In most cases these are placed on fertile soils, where direct competition between food and fuel production arises. The EU agricultural support regulations require *c.* 10% of European crop lands be 'set aside', in other words retired from any kind of conventional agricultural production. However, set aside land may be used for energy crop cultivation, which compromises the conservation value that fallow set-asides have, especially as habitats for farmland birds (Crabb *et al.* 1998). Currently there are few economic incentives for energy crops to encroach on marginal lands of high conservation value in central Europe, although there is concern that semi-natural grasslands might be converted to energy croplands. Therefore 'first generation' biofuels challenge off-reserve conservation in agricultural landscapes far more than nature reserves. Current energy cropping forms are largely derived from conventional intensive agricultural systems and include monoculture crops and high inputs of nitrogen fertilizer. As many biofuel crops require water during summer, irrigation is often indispensable. This leads to inefficiencies and manifold ecological disadvantages. Among these are soil compaction, soil erosion, nutrient leaching, simplified crop rotations and the loss of habitats and species (Jordan *et al.* 2007). Moreover, as the EU is not self-sufficient in food and fodder supply, the ecological footprint on landscapes outside Europe may be enlarged.

As the limits of land available to conventional energy crops become more evident, 'second generation' biofuel strategies (for example 'biomass to liquid' synfuels or 'cellulosic ethanol') focusing on biomass feedstock based on wastes instead of specific energy crops are underway. Using biomass wastes from landscapes is a double-edged sword; it may trigger low-intensity landscape use, which contributes to shaping high nature value farmland in Europe. For example, conservation-oriented management of traditional coppice forests, hedgerows or marsh lands might be enhanced. But environmentally destructive forms of residue use may also be promoted through using biomass wastes, such as intensive wood harvesting, the complete removal of woody debris and dead wood from forests, or excessive straw use from crop fields.

An estimated 83% of the global land area is already under direct human influence (Sanderson *et al.* 2002), and further extending the human footprint on land may be accompanied by highly negative ecological concomitants. But in our opinion, the basic challenge is not biofuel production itself but the way in which biomass is produced. There is a strong need for innovative land-use systems specifically designed for energy crops that both have a high energy productivity per area and support a high structural and species diversity. Potential strategies comprise the diversification of crop rotations, reductions in mineral fertilizer and biocide use, the use of a broader spectrum of crop species and varieties, the design of mixed cropping systems, longer harvest intervals and increased physical landscape structure.

One way out of the biofuels versus conservation dilemma might be to develop novel, and where available re-establish traditional, agroforestry systems on degraded lands. Agroforestry has received great attention since the 1970s due to its many positive environmental impacts and high productivity in areas suffering from marginal agricultural soils, and land and capital scarcity. For example, an alley cropping agroforestry system (a land-use system that entails growing annual crops between hedgerows of planted shrubs and trees) has been designed to produce woodfuels in a post-mining area in Brandenburg (Germany). Ten years' data indicate high productivity and delivery of considerable environmental services. Ecological benefits are derived from the diversity of woody and annual crops and the diversity of habitats that the alley structures provide for wild plants and animals. The linear structures support the genetic exchange of wild animals and counteract the fragmentation of landscapes (Grünewald *et al.* 2007). As forest productivity is high and the initial standing stock is low, the system efficiently sequesters carbon and reduces energy inputs.

Almost all of Europe's farmlands, and a large part of its forests, are in private ownership and face the typical problems of conservation on private lands. Economic realities and conservative thinking have so far favoured simply-structured intensively-managed energy cropping systems over those that are more diverse and sustainable. Alley cropping systems are not yet profitable, although they have moved towards profitability owing to rising fuel prices (Röhricht & Ruscher 2007). However, none of the European biofuel pathways would be profitable in an unregulated market. Current profit margins merely reflect the incentives given by a set of public subsidies, tax breaks and purchase guarantees (such as the EU Energy Crop Premium or the EU Biofuels Directive). For example, production costs of domestic bioethanol in Germany amount to € 0.8–0.9 l^{-1} (€ 1 = US$ 1.41, October 2007) gasoline equivalents compared to a price level of € 0.2 l^{-1} (2005 tax-free price for fossil gasoline; Henke *et al.* 2005). Electricity generation costs of a manure-based biogasification plant average € 79 $\mathrm{MW\,h_{el}}^{-1}$ compared to the conventional € 45 $\mathrm{MW\,h_{el}}^{-1}$ (for a hard coal power plant; Leible & Kälber 2005). Future profitability depends on the development of prices for fossil resources and the maintenance of public incentives.

The strong dependence of the bioenergy sector on incentives offers an opportunity to link these public expenses to compliance with conservation standards. Conservation criteria have been successfully introduced into Germany's wind and hydropower support scheme. A similar approach of developing simple but efficient conservation standards for bioenergy could help to integrate ecological knowledge and thus direct bioenergy into pathways that are compatible with issues of landscape, biodiversity and soil conservation. It is also imperative that future policies provide better incentives for biofuels with a high energy efficiency and a high potential for GHG emission reduction. There is no doubt, however, that merely replacing fossil fuels by biofuels is not enough; sustainability cannot be achieved without dramatically increasing energy conservation and efficiency.

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