STRATEGIES TO REDUCE LAND USE COMPETITION AND INCREASING THE SHARE OF BIOMASS IN THE GERMAN ENERGY SUPPLY

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ABSTRACT: Bioenergy is expected to become one of the key energy resources for global sustainable development. However, bioenergy cannot be infinite, because the land area available for biomass production is limited and a certain amount of biomass must be reserved for food and materials. Land management is a topic that has long been neglected in sustainable development of bioenergy although land is a limited resource. That is now changing, mainly due to the political support for energy crops generating an increased competition for arable land on both a domestic and a global scale. This paper first gives an overview of the different land functions and the allocation of land use. Then, focusing on the German conditions, it investigates strategies to reduce the demand for land and the negative impact of land use.
Keywords: land use, strategies, energy, biomass

1 INTRODUCTION

The availability of suitable space to satisfy the different needs for food and fodder, raw materials and bioenergy, settlement and transportation, and recreation and tourism as well as to protect nature and the climate is strongly restricted. The competition for land use is being intensified by the political goal of raising the share of renewable energy, e.g. in Germany from 6% to 12-15% of the total fuel production by 2020. In addition to electric cars using power supplied by renewable sources, biofuels are needed to reach this target.

The need for energy crops for the production of biofuel has altered the dynamics of land use, with a shift of areas traditionally used to grow food crops to growing crops for producing fuels. This change has contributed to the increase in food prices in the short run, as recently experienced in Mexico and the USA, which witnessed a substantial increase in maize prices driven by the increased demand for corn to produce biofuels. The land requirements for energy crops have also augmented the pressure on valuable ecosystems such as rain forests or grasslands, some of which have been converted into arable land to serve as production units.

2 LAND AS A LIMITED RESOURCE

The availability of land is an essential precondition for satisfying the existential needs of human beings. In the following the terms 'land' and 'soil' will be used synonymously although two different meanings are related to them. On the one hand these terms are applied to the surface and the physical space which provides area for human activities such as housing, industry, energy generation, and transportation, as well as for leisure and recreation. In this context, soil is a factor of production whose use can be subject to different claims and whose economic value can be substantial. On the other hand, every type of land use is intrinsically tied to the ecological medium 'soil' that serves as the basis for biomass production and the provision of habitats for fauna and flora, fossil energy carriers and mineral commodities.

Soil fulfils, furthermore, numerous ecological functions due to its capacities to filter, buffer and convert substances, including the fixation of carbon, which plays an important role in climate protection policies, maintenance of water and nutrients circulation, alteration and degradation of harmful substances and conservation of genetic resources. Land is also an archive for cultural and natural history.

Land cannot be consumed in the proper sense of the word; but it can be used in such a way that the spectrum of possible future uses is significantly restricted. Since the supply of land is limited and cannot be augmented, a continued increase in claims to land is neither possible in the long run nor ethical in the interest of future generations [1]. The continued loss of high-quality arable land can jeopardize the ability to feed the world's population and to produce renewable materials and energy. In some regions the limited availability of land already results in competition between different land users.

While certain forms of land use can indeed be combined – e .g. forest land can produce wood products and energy and at the same time provide habitats for plants and animals and serve as a recreation area – the main forms of land use exclude one another partially or completely. Besides, several types of land use, such as mining, intensive agricultural production and sealing as a result of roads, transportation infrastructure or residential area, impair the environmental functions of soil. Although soil can, in principal, be rebuilt, much damage to soil is almost irreversible since soil regeneration takes such an extremely long period of time [1].

In recent decades worldwide soil degradation has become more and more serious and now poses a threat to agricultural production and terrestrial ecosystems. Soil degradation, defined as lowering or losing the capability of land to provide specific functions, includes soil erosion, salinisation, nutrient depletion, physical compaction and desertification. The rate of degradation has increased considerably as a consequence of the growth in the human population and the implementation of technology. The erosion and chemical and physical degradation of arable land has been caused by a number of factors, many or most of which are tied to human development and activities such as inappropriate agricultural and forest management, settlement and infrastructure development.

The global assessment of man-made soil degradation shows that damage has occurred upon 15% of the world's total area (13% light and moderate, 2% severe and very severe). Approximately 20% of the cultivated land, 30% of forest land and 10% of grassland are degraded due to human activities [2]. Soil degradation is caused primarily by overgrazing (35%), agricultural activities (28%), deforestation (30%), and over-exploitation of land to produce fuel (wood) (7%) and industrialization (4%).

Germany and other developed countries contribute significantly to global soil degradation by importing food and feed from abroad. E.g. approximately 30% to 40% of land required satisfying Germany's hunger for food, materials and bioenergy is located outside the country's frontiers.

The limited availability of productive soil will lead to rising competition among land users as a consequence of the worldwide increase in the demand for land for cultivating energy and biorefinery crops. The current debates on food prices and the conservation of biodiversity give evidence, that this can have economic, ecological and socio-political impacts. In some regions of Germany, competition for land use between crops for food and energy production is already a reality, causing increasing prices for farm leases. On the other hand, the absence of a demand for land can also result in economic, ecological and socio-political problems. Unused land in regions of economic decline or in unfavourable locations can necessitate "nursing care" since otherwise the targets for sustainable land management cannot be met. Examples are some settled areas in the eastern parts of Germany and the grassland in the low mountain range.

3 ALLOCATION OF LAND USE

Germany is a high-tech country, but land allocation makes it obvious that agricultural and forestry production still determines its cultural landscape. More than half of the land (52.5% or around 17 million hectares) is used for the production of food, fiber and energy. Another 30% are covered with forests (see Fig. 1). Of the agricultural area, 30% are covered with grasslands, and 40% are used for the production of corn. About 13.2% are allotted to settlement and transportation, 2.4% covered by water and 1.5% allocated to a residual category, e.g. waste land and former mining land.

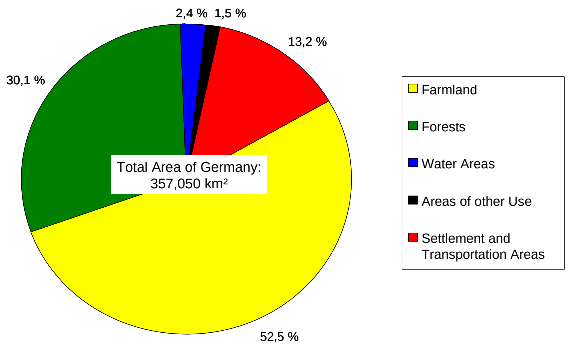

Figure 1: Allocation of land use in Germany in 2008[3]

In Germany, the area utilized for the cultivation of plants for energy and renewable materials has more than doubled between 2003 and 2007. In 2009 approximately 1.75 million hectares of land are used for energy production and another 250,000 hectares for renewable materials [4]. Crops for the industrial, chemical and energy sectors are thus being cultivated on 17% of the arable land. Of this number, one million hectares are used to grow rape (canola) for biodiesel, and another 0.5 million hectares to grow crops, mainly maize, for the generation of biogas.

The utilisation of energy crops is forced fundamentally by German legislation, such as the feed-in-tariff for renewable electricity [5] and the obligation to add biofuels [6]. These national regulations were enacted to achieve national targets for renewable energy. The intention that primarily marginal agricultural land and set-aside land should be used for energy crops has failed. Only half of the set-aside land has been used for energy cropping; at the same time, energy crops are being cultivated on productive soils that previously had been used for food production.

An increasing demand for arable land can be expected in the future due to the growing worldwide demand for food, animal feed, renewable materials and energy crops. Even today the significant use of agricultural commodities in the energy sector has led to a scarcity of productive soil around energy (for the most part biogas) plants, resulting in rising prices for farm leases. Agricultural land is required to complement the wood supply from traditional source (residues from wood cutting and saw mills).

Nature protection does not appear in statistics as a discrete consumer of land, but is pursuing the goal, to shape land use forms of main land users such as agriculture and forestry in its own sense. The inventory of species and biotopes in the cultural landscape can be conserved by agricultural practices that are ecologically sound and regionally adapted. In order to combine agricultural land use with nature conservation in Germany, an environmental agriculture programme has been launched. Thus, in 2004 approximately 29% of the agricultural areas were cultivated in the framework of this programme [7].

The protective area NATURA 2000 covers 13.5% of the German terrestrial area. In line with the national strategy for biodiversity the extension of a coherent protectorate is aspired as well as an extensive cultivation on adequate areas of the total cultural landscape. Furthermore, 5.1% of the agricultural area (2008) are cultivated by organic farming, the most natural and sustainable production system available today. This demonstrates that the land use targets of agriculture and conservation can be combined but an appropriate political and financial framework is needed in order for this dual use to become reality. At present, the strong financial support for bioenergy in Germany lowers the rate of such side by side land use.

4 COMPETITIONS FOR LAND USE

Stakeholders using land in a different way can come into conflict with each other if they target the same area at the same time. Competition for land typically arises, in urban areas, between settlement and agriculture and, in rural areas, between agriculture – and meanwhile also between crops for food and energy production – and nature conservation. In the following, these two main lines of competition for land use and the potential conflicts are outlined.

The additional consumption of land for settlement and transportation is walking back in Germany due to its shrinking population. Nonetheless, every day over 100 hectares are still taken for building. Because of the great difference in prices between urban and rural areas for the purchase of land, the demand for building land has focused mainly on the hinterland of conurbations and rural areas. Thus the designation of land ready for building does affect predominantly the agricultural area. Mainly high productive arable soils are used because centres of settlement have historically been developed in areas with high soil fertility. These land use conflicts are exacerbated through the additional land demand for the cultivation of energy crops in the surroundings of local bioenergy plants satisfying the energy demands of residential areas or industries.

Urban sprawl is increasing the length of commuting and extending traffic flows, making it more necessary to expand the traffic infrastructure. This can lead to conflicts with agriculture and nature conservation. Besides, local public transportation cannot be organised in a cost-effective way in dispersed settlements, resulting in a growing demand for private transportation.

In Germany almost half of the area used for settlement and transportation is sealed. Soil sealing produces profound disruptions of soil's ecological functions, which in turn have an impact on the entire ecosystem. Even after the sealing is eliminated and a site is re-natured, it takes a long period of time for the natural functions of soil to be reconstituted. Moreover, sealing prevents precipitation from soaking into the soil, resulting in faster rainwater runoff into the canalisation. Consequently, the natural replenishment is lower and sewage plants are overloaded, which can lead to unclean waste water passing into the discharge system.

Nowadays the traditional competition between settlement, agriculture and nature conservation is exacerbated by the growing demand for land to produce renewable energy and to slow down climate change. Biomass is certainly not the final answer to the energy issue or to carbon mitigation policies, but it can contribute to broadening the energy portfolio, permitting production systems to be distributed and unused agricultural land to be reallocated. In 2006, more than half of the area that before had been set-aside in Germany (438,000 hectares) was again used for agriculture [8]. The set-aside regulations have meanwhile been abandoned. Today biomass is the main contributor to renewable energy production in Germany, providing in a storable form the feedstock for a flexible and continuous production of sustainable fuels, electricity and heat (see Fig. 2).

Even the use of set-aside land can lead to conflicts because this land can provide important natural-like spaces for plants and animals in the intensively cultivated agricultural landscape. A second line of conflicts between farming and nature conservation targets emerges from the specific plants being cultivated and from the intensity of agricultural production. The attempt to achieve high energy yields per area can induce a more intensive cultivation of extensively used species-rich grasslands and thus to a loss in biodiversity [9].

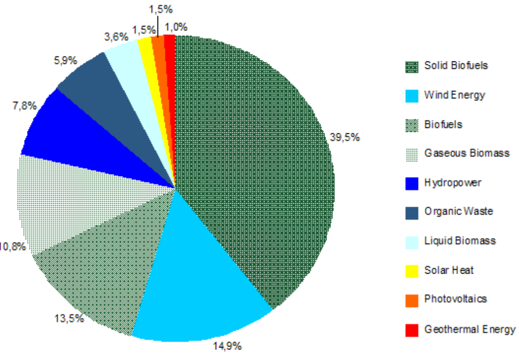

Figure 2: Primary energy consumption of renewable energy in Germany in 2008

Agricultural land use can conflict with people's aim to use landscape for recreational activities because the type of cultivation has a strong influence on the attractiveness and value of open spaces for leisure and tourism. Agricultural landscapes that are characterised by a small number of types of high-growing energy crops and that do not have structuring elements such as hedges and nature-oriented habitats are not attractive for recreation purposes. As production of biomass energy in Germany is based on only a few plants (rape, maize) which are grown in a narrow crop rotation, energy cropping has no positive effects on the recreation value of the landscape. In fact, the supply of energy crops can damage the touristic value of a landscape, e.g. if the cultivation of grassland is intensified to produce a high-quality substrate for biogas plants, reducing the species-richness. Undesirable effects can also occur from short rotation plantation of rapidly growing trees or from obstruction of characteristic views of a landscape.

5 OUTSOURCING OF LAND USE

The German goal to increase the share of biomass in the energy supply cannot be reached only by using energy crops grown domestically. Even now, significant quantities of biomass are imported to satisfy Germany's demand for food, fodder, energy and industrial raw material. Regarding industry and energy, more than half of these commodities used in 2006 were imported: approximately 55% of the biodiesel, 67% of the fuels based on plant oils and 66% of the biomass used for industry or material production [10]. This has transferred the demand for land use and the conflicts that may result to other regions, mainly developing countries. As some of these countries already produce food and fodder (e.g. soybean) for Germany and other foreign countries, this effect can exacerbate already existing land use conflicts.

According to [11], it can be assumed that the demand for land in Germany for the supply of food and fodder is approximately 20% higher than the domestic area that is available for agriculture. This large-scale outsourcing of the cultivation of agricultural products to emerging markets such as Brazil can lead to severe ecological problems (e.g. cutting down rainforests) and social disturbances (e.g. higher food prices, displacement of the indigenous population). These problems may increase in the future because of the impact of climate change, regional water shortage and soil erosion and degradation.

Scenarios analysed by the Wuppertal-Institute, UMSICHT and IFEU [12] show that only one-fifth of the German demand for biofuels expected in 2030 could be satisfied by domestically produced biomass. The imperative to import biofuels would amplify the need for crops to be cultivated in other countries. According to the results of these analyses, this additional German land demand would significantly exceed the per capita share of globally available arable land of 2,000 m^2, and would thus strengthen the pressure for expansion at the expense of natural habitats. Another result is that the reallocation of land for the production of biomass in other countries would probably release more greenhouse gases than could be saved by the use of biofuels in Germany [13].

6 STRATEGIES REDUCING LAND USE CONFLICTS

Competition for land use triggered by an increased demand for biomass for energy generation can be eased by different strategies and measures. First, the biomass required for the production of fuel, electricity and heat can be derived from residues from agriculture, the food industries, communities and households. Less land would be needed for the cultivation of energy products if this potential of unused biomass resources were tapped. Besides, converting organic residues into energy helps to prevent greenhouse gas emissions resulting from the decomposition of organic materials. Second, those energy crops that achieve high yields or do not need fertile arable land should be primarily developed, such as microalgae grown in open ponds or photo-bioreactors. Such strategies make it possible to increase the share of biomass in the German energy supply in a way that makes highly efficient use of scarce arable land and that also uses less fertile land which would otherwise have to be maintained through afforestation or agricultural “nursing”. Another strategy is to put more effort into the dual use of land, e, g, the combination of agricultural and ecological targets.

To make this vision come true, the existing agricultural production system would have to be enhanced to achieve higher yields in a sustainable way. In this regard, research activities to improve breeding and agriculture technologies will play a key role. The development of efficient and ecologically sound technologies to convert scarce biomass into high-value fuel and electricity must be part of the solution. Last but not least, the consumption pattern and lifestyles of Germany’s population needs to be addressed. A decline in demand for nutrition, settlement and transportation can lead to a significantly lower demand for land and thus reduce competition. In the following only strategies based on innovative technologies in the agriculture and bioenergy sector are elaborated.

6.1 Innovative technologies converting organic residues

In Germany, there are significant quantities of agricultural residues (such as straw and hay), residual wood (such as logging residues), unused growth from conservation areas, and organic wastes from communities and households that are available for use as sources of energy. The amount of organic residues and waste is estimated to be around 100 million tons per year [14], of which around 41% are wood residues and 36% agricultural residues (mainly straw and liquid manure). Because of technical and ecological constraints, only approximately 65% of this biomass resource could be used for energy production. This means that between 4% and 5% of the primary energy consumption could be covered by organic residues in 2030, which is about the size of the energy contribution that can be expected from energy cropping on around 3 to 4 million hectares in Germany by 2030.

Despite the great potential of organic residues and their current low costs, these materials are not yet being exploited sufficiently. The causes are technical, logistical and economic hurdles but also environmental constraints restricting their exploitation for use as a source of energy. The main technical and logistical challenges are the low energy density, the regional variability and wide distribution (making long transportation routes necessary and the use of biomass uneconomical), the periodical occurrence, the heterogeneous composition of the organic residues and their high ash and salt content. To unlock these biomass resources, further research and development as well as incentives are needed. An innovative approach to solving these problems is for example the Bioliq® concept developed at KIT. Within this process, the biomass is first subjected to fast pyrolysis in decentralized plants, producing an energy-dense intermediate composed of pyrolysis oil and pyrolysis char. The resulting bio-slurry is then reacted in a large-sized central entrained flow pressurized gasifier at pressures of up to 80 bar and temperatures above 1200°C to produce synthetic gas, from which fuels but also a large variety of other key organic chemicals can be prepared using customary chemical processes.

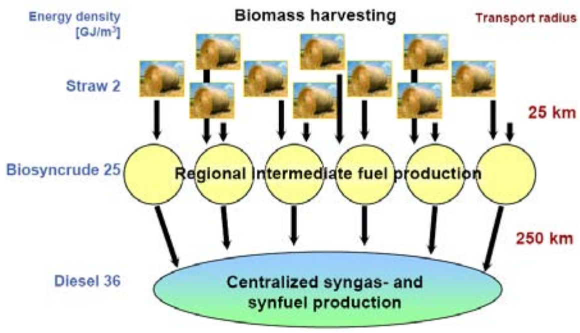

Figure 3: The Bioliq® concept for the production of energy from organic residues

The utilization of organic residues usually has a positive impact on the carbon balance, climate change and the economy. However, undesirable trade-offs can also occur if the share of organic residues taken off the land diminish the potential for carbon storage, the fixation of nutrients such as nitrogen and the build-up of humus in the soil. This can be the case if the amount of straw used for the generation of heat, electricity or synthetic fuel exceeds the amount that should be left on the field to guarantee a sustainable development of soil functions. This type of negative impact from an increased use of organic residues can be limited by setting a framework with adequate incentives and a certification system to guarantee a sustainable provision of residues.

6.2 Increases in plant yields

The yields of major crops have increased significantly in the past through progress in breeding and farming technologies. A key role in this development is played by the transfer of plant genes within or across species, which creates novel combinations and modifies genes. Hybrid genetics – the combination of different versions of the same gene – has resulted in spectacular yield increases. Corn yields in Germany have increased almost 35% in the last two decades. At the same time, the demand for fertilizer has declined by 11% for nitrogen, 55% for potassium and 63% for phosphate.

Yields and agricultural productivity are already on a high level in Germany. There is hope, that genetic engineering has the potential to raise yields and boost agricultural productivity by, for example, enhancing the ability to raise crops under less favorable conditions. Genetic modification for herbicide-tolerant soybeans and corn has, however, not led to higher yields, and insect-resistant corn has improved yields only marginally. The increase in yields for both crops over the last few years was largely due to traditional breeding or improvements in agricultural practices [15]. Thus, the report of the Union of Concerned Scientists concludes that genetic engineering is unlikely to play a significant role in increasing agricultural productivity in the foreseeable future.

In the long run, however, genetic engineering and other biotechnological techniques could contribute to further increasing yields and the amount of desired substances for the downstream process chain (e.g. amylopectin potatoes, rape high in erucic acid). This may make it possible for modern breeding techniques to design plants more efficient in using water and nutrients. Such plants could be cultivated on marginal land, which up to now cannot be used or only used by extensively cultivated plants. Although competition for land between food and energy production could be reduced in this manner, conflicts with nature conservation might be enhanced if plants traditionally cultivated on marginal soil are pushed back, with a negative impact on biodiversity. Besides, it cannot be forgotten that, among a major part of the population, there are strong ethical and ecological concerns regarding the use of genetically modified plants.

6.3 Microalgae as an additional biomass source

The cultivation of plants with high biomass yields can reduce the land use for food and energy production. Yet high yields can only be attained for some plants, such as oil palms, and if the plants are grown in regions with an optimal temperature and supply of water and nutrients. The need for alternative biomass feedstocks that are not in competition to food production has drawn attention to microalgae. The advantages of microalgae as an alternative biomass feedstock are significantly higher yields per area compared with terrestrial crops, less or no use of fresh water making cultivation in arid regions possible, and a lower dependency on seasonal variations of yield. Biodiesel can be obtained with microalgae producing oils between 420 and 3,200 GJ/ha and year, which is several times higher than the biodiesel yields from oil palms (200 GJ/ha) or rape (53) [16] (1)

Depending on the species chosen, methane, hydrogen and high-value products such as omega-3 fatty acids can be produced. Flue gases from energy or industrial plants can be used to provide the higher concentration of CO_2 needed to increase the growth of algae. Waste water can serve as a source of nutrients. However, significant biotechnical, environmental and economic challenges need to be overcome before large-scale production of algal-based fuels and products becomes economically feasible. At present, major bottlenecks are the high cultivation and harvesting costs, unfavourable energy balances, and the high consumption of nutrients. The availability of suitable algae production sites must also be identified and the ecological and social impact of agro-industrial land use in comparison to the traditional cultivation of energy plants should be assessed.

6.4 Highly efficient conversion of biomass to energy

The yields of net energy per hectare in Germany are rather small when traditional techniques and processes are employed. This is due to the fact that only a part of the biomass cultivated can be used efficiently for energy generation. For example, only the oil fraction of the rape seed is converted to biofuel. In contrast, protein-rich rape meal and lignin-rich rape straw are used for other purposes, such as the production of feed and the enhancement of the humus content in soil. Distinctly higher energy yields per hectare can be achieved if special energy plants are used and if there are techniques to convert this biomass in an efficient way into valuable and storable energy products (fuel and electricity). This would be the case if fast-growing trees could for example be converted into designer fuel using biomass-to-liquid techniques. Great hopes are focused on biotechnological processes such as the enzymatic decomposition of ligno-cellulosic materials. Another interesting technique for a complete conversion of solid biomass is thermo-chemical biomass gasification for the production of fuels (biomass-to-liquid / btl) or chemical products (bio-refinery). Depending on the basic material, the process and the side products (e.g. electricity and heat), the fuel yield can be different: For example, using btl, between 1,800 and 3,000 l of fuel equivalent can be generated per hectare and year compared to 1,400 l of biodiesel from rapeseed and 1,600 l of bioethanol from cereals [17].

7 OUTLOOK

Sustainable development calls for comprehensive and integrated strategies for managing scarce land resources. There is no such concept in Germany. On the contrary, the co-existence of conflicting political goals concerning the extent and type of land use (agriculture, settlement and conservation) and the strong political support for renewable energy do lead to competition and conflicts. Decisions on land use are long term and extremely difficult to revise. Even if arable land is used for annual crop production, this decision cannot be changed easily because of the investment made in downstream energy conversion plants (e.g. biogas plants) or long-term contracts with industries. Decisions regarding land use for settlement and transportation are even more fixed because of the longevity of building structures.

Innovation and technical progress in the utilization of organic residues as energy source and in the conversion of biomass to energy can lead to a more efficient use of available biomass and thus reduce the demand of land for energy purposes. The increase in plant yields by breeding and the use of genetic engineering and automation in agriculture can lead to a more efficient land use. On the long term the scientific and industrial development of algae production systems for bioenergy production could reduce the demand of fertile land and extend the biomass production to marginal land and deserts or seawater areas. To exploit the potential of these technical options and thus to alleviate land use competition requires not only strong efforts in public and industrial research and development but also a socio-political, economic and legal framework that facilitates the development, implementation and diffusion of innovative measures in these fields.

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9 NOTES

(1) These numbers are calculated according to [17] and [18]