Organic Agriculture and the Production of Biomass for Energy Use

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Abstract: Modern bioenergy is seen as a promising option to curb greenhouse gas emissions. There is, however, a potential competition for land and water between bioenergy and food crops. Another question is whether biomass for energy use can be produced in a sustainable manner given the current conventional agricultural production practises. Other than the land and water competition, this question is often neglected in scenarios to meet a significant part of global energy demand with bioenergy. This article combines results from several disciplines to address this question.

Organic agriculture is one sustainable alternative to avoid the negative environmental effects often caused by conventional agricultural practises. Yet, burning significant quantities of organic matter - inherent in bioenergy use - is incompatible with the principles of organic agriculture. Thus, meeting a significant part of global energy demand with biomass grown organically may not be possible. Due to the dependence of organic farms from biomass input, bioenergy based on agricultural waste may not be a sustainable option either. There may therefore be a trade-off between policies and practices to increase bioenergy and those to increase sustainability in agriculture via organic farming.

This article is not a general critique of bioenergy but it points to additional potential dangers of modern bioenergy as a strategy to meet significant parts of world energy demand.

1 Introduction

Bioenergy[1] is becoming an ever more important option in climate change mitigation policies. The EU Directive 2003/30, for example, aims at increasing the share of biofuel use for automotive power in the EU to 5.75% by 2010 (EU 2003, from 0.8% in 2004 (EU 2005)), and in the US, various initiatives to promote research in and to increase the shares of renewable energy and bioenergy in particular are planned or already launched, as stated in the President's State of the Union address 2007 (Whitehouse 2007) or the energy bill from 2005 (US Senate 2005). This has led to the discussion of potential problems regarding land use competition between food and energy crops (Azar (2004) and references therein) and regarding competition on water and water scarcity (Berndes 2002). This competition has repeatedly become manifest, most recently by the raise of corn prices in Mexico due to increased demand from bio-ethanol factories in the US (NYT 2007).

A second line of criticism addresses the energy and emissions balance of liquid biofuels. A growing number of studies collect information on life cycle analysis of different types of bioenergy with mixed results. Bastianoni and Marchettini (1996) find unsatisfactory long-term sustainability performance of bio-ethanol, based on emergy analysis. This rather negative assessment of ethanol still prevails ten years later (Delucchi 2006), but the production process matters; ethanol from switchgrass, for example, performs considerably better than ethanol from corn. Ulgiati (2001) emphasises the potentially very low net energy yield, Pimentel (2003) points out generally negative energy balance, economic and environmental impacts, and De Oliveira et al. (2005) provide a critical discussion of ethanol from sugarcane in Brazil compared to corn in the US based on an ecological footprint analysis. Both production methods do not seem to be sustainable alternatives to replace gasoline, but ethanol from sugarcane performs considerably better than ethanol from corn. An encompassing assessment of various fuels by Delucchi (2005) and a comprehensive review of existing studies (Delucchi 2006) finds that life cycle emissions from many biofuels are higher than for petroleum fuels. Focusing on fossil fuel use and greenhouse gas reductions only, however, a wealth of studies draws a positive picture, with only a few controversial ones claiming different results (as assessed in WWI (2006)). These studies mainly refer to so-called first generation biofuels that are based on the starch or sugar contents of the energy crops. Considerable potential is expected from second generation biofuels that are based on conversion of the cellulose and lignin parts of the plants, thus utilising much more of the biomass for fuel production. These techniques are however still in an early development stage (WWI 2006).

In this paper, I want to discuss another crucial issue related to bioenergy use, namely the question how the huge amount of biomass for bioenergy use necessary to significantly contribute to global carbon dioxide emissions reductions can be produced in a sustainable way.

There are several studies that address the sustainability of bioenergy production in specific settings but in contrast to the land and water competition, the topic largely has not entered the discussion on a general level. For a sustainability assessment, different types of biomass have to be distinguished. Biomass from relatively sustainable forest use practises (see e.g. the topical issue 30(4) in Biomass and Bioenergy: Richardson (2006)) or perennial bioenergy crops on marginal or highly erodible land (Paine et a. 1996) perform differently than high-yield energy crops with annual harvest, for example[2]. As in food crop production, large-scale monoculture production of biomass is likely to be particularly unsustainable (cf. section 3 below). But even employing 'marginal land' for biomass production for energy use may well result in averse effects for local communities if not assessed with a true understanding for their local livelihood strategies (e.g. Kläy 2000, p.25).

Besides biomass specifically grown or harvested for energy use, bioenergy can be produced from biomass waste from agricultural production such as bagasse, rice husk, fruit shells from palm oil production or other agricultural residues. Using these resources for energy production is more sustainable than having them decay without use and with considerable methane emissions. The sustainability of burning these resources for energy production can however be questioned in the context of their potential use as fertiliser under sustainable agriculture practises (see section 4).

This paper attempts to contribute to the discussion on sustainability of bioenergy production on a general level by combining knowledge from different disciplines, mainly from agricultural sciences and (bio-)energy systems. It relates a potentially huge production of biomass for energy use or a potentially huge demand for agricultural waste to the sustainability of current agricultural production systems and to alternative agricultural production practises. I formulate the hypothesis that an aim to provide both sustainably grown agricultural products and bioenergy, should they contribute significantly on a global scale, adds another sphere of potentially strong competition to the one on land and water between food and energy crops.

How to judge sustainability of bioenergy on a project level and for specific biofuels is a topic of ongoing discussion. Jürgens and Muller (2007) present several existing sets of sustainability criteria for bioenergy projects in comparison with sustainability indicators for general climate change mitigation projects and identify an important mismatch especially for issues related to the production of biomass. While present in many criteria sets for bioenergy, this topic is almost completely lacking in the general sets of criteria. But also in the bioenergy context, the sustainability discussion is mainly confined to specific situations and crops and does not relate to aggregate effects on a global level (cf. above and endnote [1]). An exception is Rejinders (2006) who discusses in detail potential negative impacts of any bioenergy production extracting large parts of biomass on soil characteristics and ecosystem services. In this paper, I present a more systemic view of such issues, relating them to conventional and to sustainable agricultural production systems. Similar to the results of Reijnders (2006), this further motivates the necessity to incorporate a truly encompassing sustainability assessment into the discussion of climate change mitigation options based on bioenergy.

A caveat to the criticism I present here is in place. The criticism I want to put forth in this paper is general and addresses 'modern'[3] bioenergy as an option to meet a significant share of total global energy demand, say 15 to 20% (see the following section for a motivation of this amount), also in industrialised countries. On a project level and duly adapted to the local situation, there are many promising options: The use of crop residues otherwise dumped or burnt on the field can lead to considerable improvements of local environments while at the same time producing power or biogas. Small-scale on-site bioenergy systems bear considerable potential to increase livelihoods and to work towards poverty reduction especially in rural areas, e.g. by contributing to replacing fuel wood by biogas (see section 4 for some examples). A recent and detailed overview on the several potentially problematic aspects of bioenergy, especially in developing countries, can be found in IFPRI (2006). The big potential of bioenergy to contribute to sustainable development is acknowledged, but the potential problems have to be taken into account and many important questions still remain unresolved.[4]

The following section presents the basic interrelations between agriculture, land use, water scarcity and bioenergy. Section 3 shortly addresses the main problems of conventional agriculture. Section 4 presents the principles of organic agriculture and the hypothesized incompatibility with bioenergy production on large scales. Section 5 concludes.

2 Basic Figures: Agriculture, Land Use, Water Scarcity and Bioenergy

The total global area currently used in agriculture (arable land and permanent crops) is about 1530 Mha (year 2000, FAO 2006a). Potential arable but not yet used land for rain-fed agriculture is estimated to be about 2800 Mha, whereof 45% are covered with forest. However, much of this land is needed to preserve forest cover and for infrastructural development. Accessibility puts further constraints to any substantial expansion. In addition, these land reserves are distributed very unequally. More than half of them are located in seven countries only (Angola, Argentina, Bolivia, Brazil, Colombia, DR Kongo, and Sudan (FAO 2002b)). Additional 200 Mha are available when irrigated in developing countries. How much of these total land reserves will be available for agriculture in 50 or 100 years is far from clear, however, because of losses in arable land due to soil degradation and water scarcity in the context of conventional agricultural systems (DFID 2004 and references in Eyhorn 2007), and as it is likely that climate change will on aggregate negatively affect agriculture and the suitability of land for farming in not temperate climate zones (IPCC 2007).

Azar (2004) assumes a maximum availability of 200 EJ/year from biomass as a reasonable estimate for the potential of bioenergy use. The review of 9 future bioenergy supply scenarios given in Bauen et al. (2005) shows that 7 identify a potential of 100 - 250 EJ/year in 2050. The total range of these 9 studies investigated is somewhat larger though, from 100 to 450 EJ in 2050. Berndes et al. (2003) assess a larger but partly overlapping set of 17 bioenergy potential studies. They report a similar range, from 100 to 400 EJ/a in 2050. Hoogwijk et al. (2005) present a more detailed and recent assessment of the bioenergy potential in four IPCC-SRES land-use scenarios. They find a higher total potential with a range between 130 and 410 EJ/a in 2050 on abandoned agricultural land and an additional potential of 35 to 245 EJ/a in 2050 on the partly available other land area.

In the model of Azar (2004), the global population would be 10 bill. people by the year 2100 and it is assumed that each global citizen would consume services corresponding to about the same amount of primary energy as the average OECD citizen today, i.e. corresponding to a per capita primary energy consumption of about 200 GJ/year. By 2100, half of it would be met by energy efficiency measures. In his model, the assumed bioenergy supply would then account for more than a fifth of global primary energy supply to be generated by biomass by 2080 (dropping to about a seventh by 2100, in absolute terms decreasing by about a fourth). Gross estimates indicate then that the corresponding energy crops would use about 500 Mha, i.e. an area equalling a third of the currently used area in agriculture. Per se, these 500 Mha may not seem that big a number in relation to the 3000 Mha from above. However, only a fraction of those 3000 Mha will realistically be available (see above), the distribution of this soil resource is also important, and population growth over the next century will result in growing demand for food and land. This suggests a potential competition for land between food and energy crops (see also the general discussion in WWI (2006)).

Azar (2004) investigates the effects of such an expansion of land use due to biofuel demand on land rents and crop prices. This addresses the first shortcoming of existing studies on bioenergy availability as identified by Berndes et al. (2003): "...the studies do not provide much insight into how the expanding bioenergy sector will interact with other land use". By the end of the century, food crop prices would reach levels three to five times as high as today. Some rise in food prices from the currently very low levels would benefit the farmers. With too high prices, though, negative impacts could dominate, especially on the landless and the urban poor. In 2006, 850 mill. people were undernourished (FAO 2006b). Although a large part are smallholders and farmers or agricultural workers, it is not clear if they would benefit from higher land rents and food prices. The interactions are complex and effects are different for different groups. This is illustrated, for example, by some case studies in the context of increased land rents and crop prices due to increased demand for a particular crop. It is found that potential profits might well be captured by powerful large producers and lobbying groups (as with soy beans in Brazil (Fearnside 2001)). It is further expected that the already vulnerable part of the societies will be suffering from the direct effects of climate change itself, independently of a potentially increasing food-energy crop competition (IPCC 2007).

A second issue recognised as a potential problem for bioenergy and discussed in detail in Berndes (2002) is the interaction of increased biofuel production with the projected increased water scarcity in many developing countries and the corresponding increase in dependence from cereal imports ("virtual water"). While specific statements are difficult to provide, Berndes (2002) concludes that "...assessments of bioenergy potentials need to consider restrictions from competing demand for water resources." Like malnutrition, water scarcity is not a matter of total availability of supply but of distribution. From now 450 mill. people living in water scarce or stressed countries (i.e. not able to assure the minimal demand of 1700 m^3/cap/a for the population), this number is expected to rise to some 2800 mill. by 2025 (UNEP 2002). It is likely that higher food prices will considerably affect these nations as a whole. Most of the nations importing cereals today are oil-rich and/or do not belong to the low-income countries as classified by the World Bank, but many countries that will become net cereal importers in the future are poor and hence unable to afford to purchase cereals. On the global scale, it is estimated that water scarcity will be the driving force of about 25-30% of the global cereal market (Yang et al. 2003).

Besides competition for water and land between food and bioenergy crop production, direct competition for biomass for different use is also an issue. The Project Development Documents (PDD) of the Clean Development Mechanism (CDM) provide a number of examples. Bioenergy projects may constrain fuel supply for local industries such as brick makers[5]. Such projects resulting in increased demand for biomass could also affect farm practises relying on composting crop residues, etc. and using them as fertiliser. From an economic point of view, this is no problem, as it is a local or regional readjustment to allocate the raw material to the most efficient use and thus reflects market mechanisms. These effects are thus not technical but pecuniary externalities only. Nevertheless, such changes in local or regional structure can potentially have adverse effects and counteract the general goal of poverty alleviation if the new activities do not offer or are accompanied by viable income alternatives for the population or by other measurements to avoid hardship. The competition on the crops itself, such as mentioned above for corn in Mexico/US (NYT 2007), may serve as a drastic example of the short term adjustment problems that might occur. Competition for the biomass itself can arise in various contexts of alternative use. Below, I will discuss the issue of biomass as a fertilising input to organic farming vs. biomass for energy use. Gielen et al. (2001) discuss the potential competition between bioenergy and biomaterials that may even lead to suboptimal outcomes regarding greenhouse gas emission reductions in case of narrow policy recommendations focusing on promotion of bioenergy alone.

3 Conventional Agriculture

One main problem with the proposal of bioenergy as a valuable globally significant option to reduce greenhouse gas emissions is the neglection of the production process. There are detailed studies acknowledging this to a certain extent (e.g. Krotscheck et al. (2000), pointing out the particular relevance of fossil fuel and fertiliser use in an ecological assessment of bioenergy production), but in many overview or outlook studies, bioenergy is, regarding availability, often seen somewhat similar to fossil fuel: It is assumed to basically be available, subject only to the availability of land and inputs of labour and capital. Thus the production process for biofuel in common economic models is not modelled in any more complex manner than oil or gas extraction and refining. However, as adequate the simple picture of extraction for general assessment of fossil fuels may be, as the production took place millions of years ago and does not matter anymore, it is not adequate for agricultural production.

Agricultural production has to take place annually now and in the future. To grow plants is a highly complex process that involves much more than only land, capital and work on such an aggregate level. This is evident when looking at how highly unsustainable conventional agriculture often is. Expansion of agricultural land is one of the most significant human alterations of the global environment and conventional agricultural production has often adverse effects on ecosystems. Problems regarding long-term sustainability arise on local, regional and global level (Matson et al. 1997). The Global Environment Outlook 2 (UNEP 2000), for example, identifies the increasing nitrogen loading (whereof 60% are due to inorganic fertilisers used in conventional agriculture) as one of the major global environmental challenges. Acknowledging its immense successes regarding crop yields and food security (Evenson and Gollin 2003) and that it relieved poverty for hundreds of million of people between 1965 and 1990 (IFAD 2001), the green revolution (based on monocropping with high yield species, irrigation (where available) and increased use of chemical fertilizer, herbicide and pesticide input) also led to degradation and salinisation of soils, degradation and overuse of water bodies, loss in biodiversity - a list that could be prolonged (DFID 2004 and references in Eyhorn 2007). Besides these adverse environmental effects, it has to be stressed that a large part of the rural poor gained little from the green revolution and that poverty reduction through these techniques has slowed down. After forty years, this heritage has left a negative legacy in many countries (Matson et al. 1997).

It is unclear if this high intensity agriculture can be further sustained. A further large increase in these production techniques due to the increase in biomass demand for bioenergy would exacerbate this problem. There is some awareness of the potential difficulty to sustainably produce this large amount of biomass in the climate community (e.g. Schlamadinger et al. 2001). But in contrast to land competition, it has never really entered the discussion (cf. also the discussion in the introduction above). Giampietro and Ulgiati (1997) are a notable exception arriving at dull perspectives for the sustainability of large-scale biofuel production, based on prospective land, water, labour and pesticide requirements and other impacts on society. Similarly, WWI (2006), a very detailed report, points out many challenges for bioenergy on a global level but adopts a generally positive view. Lewandowski and Faaij (2006) point out potential problems of biomass production (such as deforestation) and identify desirables for a certification system for sustainable bioenergy, with a focus on international trade in biomass for energy production.

4 Sustainable Bioenergy Production?

To avoid the problems of conventional agriculture, biofuel would need to be produced sustainably. There are basically two ways - using waste biomass that would otherwise be unused and decay, or growing bioenergy crops sustainably. There are several approaches of “sustainable agriculture” (Eyhorn et al. 2003). Most widely accepted are the principles of organic agriculture and forestry management, which I will discuss below in section 4.1 I will argue that production of energy crops in organic farming systems faces fundamental incompatibilities. One option to sustainably grow biomass for energy use may be some forestry systems, where nutrient loss can be kept on a low level by on-site foliage and reapplication of wood ash, for example (IEA 2002). How sustainable these practises are in the very long-run, however, needs further investigation and paradigms of sustainable forestry and development of adequate sustainability indicators are still subject to discussions, especially in the light of its increasingly important role in the bioenergy context (Smith 1995, Kimmins 1997, Moffat 2003).

Using waste biomass for energy production may be less problematic at first sight, but I will argue that also this strategy faces incompatibilities if combined with organic agriculture (see below). Using biomass waste for energy production eliminates the negative side effects of open biomass waste burning or deposition and generates useful heat and power as well. Examples are waste from rice (rice husk), sugar (bagasse) or palm oil (fruit shells) production. A large number of such projects are realised under the CDM and detailed information is available from the PDDs (UNFCCC 2007). As already mentioned in the introduction, the sustainability assessment of such projects is, however, no easy task (Jürgens and Muller 2007).

Biogas production from organic material by capturing methane from anaerobic fermentation of dung and manure can be another option for sustainable bioenergy. Bath et al. (2001) present a study on dung-based biogas. Such projects are also realised under the CDM, e.g. the biogas projects on household level Begapalli and Biogas Nepal Activity I and II or industrial projects based on swine manure (UNFCCC 2007). The raw material is no waste anymore and the fermented material can be applied as a high quality fertiliser.

Although it is thus questionable if a restriction to truly sustainable sources could supply the amount of biomass needed in order to provide a significant share of global energy use, these energy sources can clearly be relevant on the farm or maybe at the community level.[6].

4.1 Organic Agriculture and Closed Cycle Resource Use

The principles of organic agriculture are, as stated by the umbrella organisation for the organic movement IFOAM (International Federation of Organic Agriculture Movements, IFOAM 2006),

- the *Principle of health*: Organic Agriculture should sustain and enhance the health of soil, plant, animal, human and planet as one and indivisible;
- the *Principle of ecology*: Organic Agriculture should be based on living ecological systems and cycles, work with them, emulate them and help sustain them;
- the *Principle of fairness*: Organic Agriculture should build on relationships that ensure fairness with regard to the common environment and life opportunities; and
- the *Principle of care*: Organic Agriculture should be managed in a precautionary and responsible manner to protect the health and wellbeing of current and future generations and the environment.

or, as in a paraphrase by Eyhorn et al. (2003):

> "Principles and Aims of Organic Agriculture - A System Approach:
>
> Conventional farming puts its focus on achieving maximum yields of a specific crop. It is based on a rather simple understanding:

> crop yields are increased by nutrient inputs and they get reduced through pests, diseases and weeds, which therefore must be combated. Organic agriculture is a holistic way of farming: besides production of goods of high quality, an important aim is the conservation of the natural resources fertile soil, clean water and rich biodiversity. The art of organic farming is to make the best use of ecological principles and processes. Organic farmers can learn a lot from studying the interactions in natural ecosystems such as forests."

Organic agriculture is often criticised for achieving too low yields to feed the world. I therefore report some of the available scientific information on yields in organic production systems. Drinkwater et al. (1998) report no significant differences between conventional and organic farming in yields for maize and Maeder et al. (2002) report 20% lower yield in organic farming on average, but with 30 to 50 % lower fertiliser and energy input, and almost no pesticides. See also FAO (2002a) and Eyhorn (2007) and references therein for a general assessment and some socio-economic aspects. The studies on yields have predominantly been undertaken in temperate climate zones and there are hardly any studies on the performance of organic farming in the Global South. Based on a review of some case studies, Parrott and Marsden (2002) conclude that yields in organic farming systems in the South are not lower than for conventional systems. This is also the result of a study on cotton in Madhya Pradesh, India (Eyhorn 2007).

Organic agriculture focuses on nutrient cycles, soil protection, crop diversity and bio-control of pest and weeds in organic farms. These issues are closely interlinked, but for the argument of this paper, the first point is most important. Nutrient cycles are closed with the help of composting, mulching, green manuring, crop rotation, etc. and nutrients exported from the farm with the sold produce (food, cotton, etc. - or biomass for energy use) need to be replaced in some way. Food export from the farm is only a part of the total biomass grown, whereas for bioenergy, it can approach close to 100% (e.g.

if all crop-residues are combusted). This material is taken away and burned, which severely interferes with closed nutrient cycles. Most plants can only take carbon and oxygen from the atmosphere (by photosynthesis from CO_2 resp. by plant respiration of O_2), some species nitrogen as well (e.g. Legumes by symbiosis with microbes). But most nitrogen and all the other nutrients are supplied via the soil. Thus either the stock of nutrients in the soil is run down, which is clearly an unsustainable solution, or it is replaced either by natural or chemical fertilisers. For bioenergy production mainly the latter option is available and the possibility of sustainable production is therefore questionable. Ash recycling does not solve the problem as ash is a mineral fertiliser containing mainly kalium, calcium and trace elements. It has to be complemented by other fertilisers to deliver organic matter, phosphorous and nitrogen (Eyhorn et al. 2003).

Clearly, bioenergy also builds on closed cycles - but only for carbon, while the limits for sustainability on farm level are rather set by a closed nitrogen cycle (Tilman 1997). For bioenergy, the carbon cycle also matters only on the most elementary level of carbon as a chemical element and as a part of the atmosphere in the form of the structurally very simple carbon dioxide. The closure of the cycle is achieved by requiring that as much CO_2 is to be taken from the atmosphere as is emitted by burning the fuel. In contrast, the cycles in organic agriculture are not closed on the level of chemical elements but rather of the more complex compounds contained in organic material. In consequence, soils under organic agriculture are usually higher in organic matter content, biological activity, and less vulnerable to erosion. Biodiversity is also higher and the crops can profit from root symbioses and exploit the soil better (FAO 2002a). These services cannot be delivered by inorganic chemical fertilisers focusing on nutrient input on the much lower complexity level of chemical elements. It thus seems to be impossible to burn biomass to a significant extent in the context of an organic farming system.

4.2 Sustainability and Bioenergy

The approach of organic agriculture is significantly different from what seems to be seen as sustainable in parts of the bioenergy community - compare for example the recent volume in "Biomass and Bioenergy" on this topic (Vol 28, Issue 2). Organic farming is an explicit topic only in one article dealing mainly with possible on-farm use of bioenergy like short rotation coppice (Jorgensen et al. 2005). However it claims one goal of organic farming to be to reduce non-renewable energy use and correspondingly focuses on this and less on the question of closed nutrient cycles. The other papers address various aspects of bioenergy production but the discussion lacks an encompassing view of its sustainability in the context of agricultural production and forestry. This volume gives valuable and interesting insights on bioenergy for a small-scale use but does not address the basic problems if it is employed on large-scales and in quantities to supply significant shares of global energy consumption.

The IEA Bioenergy position paper on sustainable production of woody biomass for energy (IEA 2002) may serve as another interesting reference. It reports how biofuels are produced today:

> "Large-scale production of biomass with willows and poplars (mainly undertaken in the Northern Hemisphere) is done through agricultural approaches, and the silvicultural systems used resemble agricultural ones. These systems include site preparation by ploughing, discing, harrowing and herbicide application, followed by machine or hand planting of dormant cuttings about 20-25 cm long. The application of fertilizers and herbicides ensures sufficient nutrient levels and weed control."

This is not judged as unsustainable, what is clearly the case from an organic agriculture point of view. So it is not clear if the IEA Bioenergy community supports these practises or not. But the (environmental) sustainability criteria listed later are of such an unspecific kind, that concrete sustainable solutions to the problems implicitly addressed in this statement (nutrient levels, pest control) and others (water use of alien species, biodiversity) are not given. It only states that heavy plants should only be used on dry or frozen soils, that nitrogen is abundant as the leaf matter is left on the field and that ashes can be redistributed in the forest as a fertiliser. This is clearly better than doing nothing but does not define a balanced back-flow of organic matter. Eucalyptus plantations are mentioned as one possibility of energy-crops, for example, without referring to the considerable potential problems of this crop as it is currently cultivated, namely its water demand and the problems of intensive monoculture plantations (Binkley and Stape 2004).

Another example are Bhattacharya et al. (2003) who employ the requirement to not compete for land with food production as a sustainability criterion for bioenergy. This is clearly an important criterion but does not address the unsustainable production practises of conventional agriculture. It would also require concerted international regulatory actions to avoid primary land to be used for energy-crops instead of food production if higher profits can be made in the former sector. An older paper by Hanegraaf et al. (1998) proposes sustainability criteria for bioenergy production in Europe. This mainly amounts to sustainability criteria for conventional agriculture with a bioenergy focus. It is clearly necessary to have such criteria at hand to assess current practises, but it does not address the potential incompatibility of sustainable closed nutrient cycles and bioenergy production. An encompassing overview of sustainability criteria for bioenergy is collected in Jürgens and Muller (2007). These criteria mainly apply on project level and do not discuss further-reaching issues of bioenergy at global scales.

5 Conclusions

Bioenergy is seen as a promising option to reduce GHG emissions. Correspondingly, policy and state assistance is steadily increasing, bioenergy use is extending and technologies are developing fast. However, the long-term impacts from a large global supply volume of bioenergy production need to be analysed in more depth. Sustainable policies must also include aspects other than avoided greenhouse gas emissions. Besides the reservations tied to food price and land rent increase due to food-energy crop competition, there are reservations regarding the increasing water scarcity and, especially, regarding the way bioenergy is grown on the fields.

This study suggests several conclusions. First, there seems to be a mismatch between criteria for sustainable bioenergy production and criteria for organic agriculture. Current production practices of biomass for energy use thus might not be sustainable. Biomass from some forestry practises or from some crops on marginal land may have best chances to be sustainable.

Second, biomass production for energy use in large volumes may be essentially impossible if it is done in a truly sustainable way (e.g. according to the principles of organic agriculture), based on closed nutrient cycles, where the biomass that is not exported from the farm in form of the final product, is reused on the farm as fertiliser (via composting, mulching, etc.). In such a farming system, as much biomass as possible should be reused on the farm, as availability of enough biomass is in fact often a problem for the organic farm. This is clearly accentuated the more biomass is exported from the farm (Eyhorn et al. 2003).[7]

Third, bioenergy from agricultural waste may have more potential to be sustainable, in particular in a context of conventional farming systems. But it is not clear how much of such residuals would actually be available for energy production in a region of largely organic farming practises, due to their dependence on a sufficient supply of biomass for their functioning and as biomass is usually not abundant on organic farms.

In case of increased organic production, e.g. due to sustainable development policies to reduce the negative impact of conventional agriculture or as a livelihood strategy for marginalised farming communities[8], or because of a general increase of demand for organically grown products, competition for biomass between bioenergy and organic farming systems could thus emerge. This could also happen on a regional level, in case establishment of bioenergy plants threatens organic farming initiatives in the same region due to their biomass needs.

Biomass quantities on a scale to meet a significant part of world energy demand thus may only be available in conventional agriculture. This trade-off should be kept in mind while designing policies for a sustainable world energy system. The bioenergy option may lead to a lock-in situation, where sustainable agriculture is not possible. This is an important potential trade-off between policies to increase bioenergy and those that aim to increase sustainability in agriculture via organic farming.

Research is going on concerning the energy crop yields of different types and on how they can best be grown (e.g. Maier and Vetter 2004). A research project specifically dedicated to the production of bioenergy in organic farming systems started in Danmark in 2006 (Darcof 2007). Judging from the planned research, it tries to clarify several essential issues but does not directly address the potential problems of bioenergy discussed here. More research is needed to decide on a scientific basis if biomass for bioenergy can be grown sustainably at large volumes or how large volumes of waste biomass can be extracted from organic farming systems without harming their functioning. This article adds to assessments of the effects of bioenergy production on ecosystem services such as Reijnders (2006). Such studies can point to potential unsustainable aspects of bioenergy and may motivate cautiousness as long as uncertainty prevails.

I want to close with a personal note. I do not want to generally criticise bioenergy. As already mentioned above, I emphasise that small-scale bioenergy has a potential, e.g. the use of biogas from composting on the farms, or in the context of extensive forest management as it is done now in many places. I also want to emphasise that I do not think that prolonged fossil fuel use, new large-scale investment in nuclear power, large-scale carbon sequestration (e.g. in the deep sea or in depleted oil-fields) are viable options to be preferred to large-scale bioenergy. I think that the problem is the scale of energy use itself: Independent of which energy sources are chosen to replace fossil fuels - personally, I think that the mere scale at which this has to take place is likely to generate problems. I thus see solutions to the energy problem especially in measures to reduce energy demand rather than in measures to develop sustainable energy supply. A considerable potential can be seen in increased energy efficiency. Energy efficiency accounts for huge savings in the calculations of Azar (2004), for example, and builds a basic idea of the 2000 Watt society with its drastically reduced energy consumption (Jochem et al. 2002). Increased energy efficiency aims at providing the same services with less energy use. Personally, I see an even bigger potential in reduced services. This refers to the ongoing discussion on "sufficiency" as opposed to "efficiency" (see the recent and comprehensive book of Princen (2005), for example). I think that this potential is not yet sufficiently tapped and that it does not yet have the status it deserves in the discussion. "Reduction" is not easy to achieve and any strategy to actually reduce energy services will be accompanied by major social changes. Changes in mobility, in consumption levels, in judgements on what is the "quality of life".

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Notes

[1]Bioenergy: energy from biofuels; Biofuel: fuel produced directly or indirectly from biomass;Biomass: material of biological origin excluding material embedded in geological formations and transformed to fossil, such as: fuelwood, charcoal, agricultural wastes and by-products, energy crops, livestock manure, biogas, biohydrogen, bioalcohol, microbial biomass, and others. Bioenergy includes all wood energy and all agro-energy resources (FAO 2004a).

[2]See however Sims and Riddell-Black (1998) as an example, discussing short rotation forest crops, that have potential for a sustainable bioenergy production scheme if duly managed in combination with waste-water treatment. See also Scott and Dean (2006) who report productivity losses due to whole tree harvesting that could be remedied by moderate fertiliser input. The overall sustainability of this practise requires further analysis but the energy efficiency seems high. Adegbidi et al. (2001) and Heller et al. (2003) investigate willow plantations with a focus on potential problems related to nutrient removal and fossil energy input in the whole production process, respectively.

[3]'Modern' biomass refers to efficient state-of-the art systems to burn biomass directly or to convert it into liquid fuels or into gas used in adequate motors or stoves. 'Traditional' biomass is mainly used with very low efficiency for cooking in many developing countries. Examples for traditional 'biomass' are fuel wood, charcoal and dung cake. Currently, 'traditional' biomass accounts for roughly 10% of global primary energy supply. Only a fraction of 'traditional' biomass is renewable as it is usually not produced in a sustainable way (Goldemberg and Coelho 2004). 'Modern' biomass is expected to also replace the 'traditional' biomass currently used.

[4]These questions concern, in particular, implications for the poor and the environment. It is also emphasised that the public sector has an important role to play "...because most of the environmental and social benefits and costs of bioenergy are not priced in the market, leaving bioenergy development entirely to the private sector and the market will lead to bioenergy production and processes that fail to achieve the best environmental and social outcomes." (IFPRI 2006, Brief 1).

[5]An example is the CDM project with reference Nr. 0476 (UNFCCC 2007), where such a switch is mentioned, but it is not assessed if the brick kilns switch to other fuels, and if so, of which type (more/less efficient and polluting) or stop production.

[6]As with many innovative practises, though, the socioeconomic perspective is central and due account has to be paid to firmly anchor such new on-farm energy use practises in the community - otherwise efficient implementation is at risk. Bhat et al. (2001) describe some accompanying measures that were crucial for the success of biogas plant dissemination in southern Karnataka, India

[7]It has to be noted that not all agricultural residues are similarly ideal as a single base for organic fertilisers e.g. produced by composting. The raw materials for a good compost should be balanced between material with a high carbon/nitrogen ratio, with a low carbon/nitrogen ratio, and bulky material with rich structure (Eyhorn et al. 2003). Rice husk and sugar cane bagasse with their particularly low nitrogen content, for example, can only provide a fraction of the material for balanced composting. Thus, rice husk and bagasse based bioenergy projects - or projects based on any residue abundant in a region and not appropriate as a single basis for good compost or mulching - may be less problematic than projects based on other residues. Nevertheless, they can be used to produce compost or as a source for biomass in general and an organic strategy may well depend on their availability in case alternatives do not abound, given the general tendency of scarcity of biomass on organic farms.

[8]See India, for example, in its 9th and 10th Five Year Plan, wherein organic agriculture is substantially promoted on a national level (FAO 2003).

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