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Environmental, Social and Economic Aspects of a Sustainable Biomass Production

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Abstract: Biomass production should always follow principles of sustainability. This paper describes some effects of biomass production for energy within environmental, social and economic contexts. Important parameters for comparing different biomasses are energy yields per hectare or CO_2 mitigation costs. However, most bio-energy production chains obviously cannot compete with non-agricultural alternatives for CO_2 emissions mitigation. The "good example" of paludiculture is where biomass production for energy is able to meet all requirements of sustainable production.

Key words: Biomass production, energy, CO_2 mitigation costs, organic soils, peatlands, paludiculture.

1. Introduction

One of the most important challenges of the century worldwide is to reduce greenhouse gas (GHG) emissions for climate change mitigation by the replacement of fossil fuels [1] with renewable energies such as wind energy, hydropower, solar electricity and geothermal energy [2]. According to the German Council for Sustainable Development sustainability means to equally consider environmental, social and economic aspects. Thus, future-oriented management means: we have to bequeath to our children and grandchildren an intact ecological, social and economic system. One cannot be achieved without the other [3]. Typical sustainability concerns include the replacement of tropical rainforest by energy crop plantations, GHG emissions associated with biomass production and processing, as well as social issues such as land rights and labour conditions [4].

Biomass production can be sustainable, if the method of land management is adapted to the site and its natural conditions. The natural potential of soils should be considered and be either maintained or enhanced by the cropping and management scheme. The natural functions of the site should be regarded and necessary changes be minimized. This reduces environmental impacts (e.g. ground water pollution, GHG emissions, erosion), includes the consideration of possible impacts on natural biodiversity and facilitates long lasting utilization of the site. Habitats for site typical species should be provided coincidently on site. From economic and social points of view biomass production should create net value added, provide employment and ensure long lasting sufficient income for people involved. This paper investigates how biomass production for energy may influence environmental, social and economic contexts and gives an example of sustainable biomass production on wet organic soils (re-wetted peatlands).

2. Principles for sustainable biomass production

Several authors formulate principles for biomass production, describing minimum demands for sustainability [5-7]:

1) The greenhouse gas balance of the production chain and application of the biomass must be positive and the biomass production must not be at the expense of important carbon sinks in the vegetation and in the soil.

2) The production of biomass for energy must not endanger the food supply and local biomass applications (energy supply, medicine and building materials).

3) Biomass production must not affect protected or vulnerable biodiversity and will, where possible, strengthen biodiversity.

4) In the production and processing of biomass the soil, ground and surface water, and air quality must be maintained or even improved.

5) The production of biomass must contribute towards local prosperity and the social well-being of the employees and the local population.

3. General aspects of the production of biomass for energy

The different options for energetic utilisation of biomass as a raw material for energy production differ strongly in production efficiency. Hampicke [8] considers ethanol production from wheat, biodiesel from rape seed and biogas from corn as unsuitable ways of producing bio-energy because of their low total performance per hectare per year (table 1). A survey report of the Scientific Advisory Board of the German Federal Ministry for Food, Agriculture and Consumer Protection (WBA) [9] comes to similar conclusions. It suggests development of only high performance biomass production chains should take place.

Table 1. Energy production by different types of biomass per hectare.

Product (at a yield of … t DM/ha * a)	Performance (kW/ha)	Performance (kWh/ha)
Ethanol from wheat (7.7)	1.1	9,899
Biodiesel from rape seed (4.5)	1.2	10,512
Biogas from corn, only electric power (15)	1.8	15,417
Willow short coppice (9); heating, efficiency 70%	3.1	26,191
Common Reed (12); heating, efficiency 70%	3.2	28,233

changed after [8]

In addition to the provision of renewable energy there can also be other important reasons for biomass production, e.g. rural development, biodiversity maintenance, or reclamation of degraded lands. This may be the motive for supporting biomass production with subsidies and/or compensation for losses of income. On the other hand the scale of primary production in agriculture is limited and must be sufficient for human nutrition and other potential use options. Johannsen et al. [10] make an assessment of worldwide and EU-potentials for biomass as a raw material for fuel seeing the largest potentials for bio-fuels in the usage of residues and organic wastes. They come to the conclusion that if large amounts of crops were to be used as bio-fuels then the food availability for mankind"will not only be a question of equity, but also an actual deficit of food. If bio-fuel will become a necessity in the future energy system, it is crucial that vehicles will not ´eat` our food” [10].

CO_2 mitigation costs are very different for the diverse biomass and usage types (Fig. 1). Mitigation by biogas and ethanol from wheat are the most expensive options. Only the use of wood chips for heating seems to compete with the non-agricultural benchmark. The total performance of most options for mitigating GHG emissions per hectare is meagre. Also in this case the use of wood chips for heating, electricity, and combined heat and power (CHP) cycle show the best results [9,11].

Bio-energy production in Germany often depends on subsidies. This includes support by the EEG (Renewable Energy Sources Act), direct payments per hectare and other payments such as for underprivileged areas, agro-environmental schemes, etc. (European Union [EU] Common Agricultural Policy). The WBA [9] calculated that the total amount of subsidies for electric power from biogas in Germany is about 2,000 Euro per hectare. This means that these transfer payments are counter-productive, ineffective, and lead to increasing land lease fees as well as rising prices for land. Additionally they lead to increasing competition with traditional land use systems, reduction of dairy farming, transformation of grassland to arable land, and to regional dominance of corn monocropping.

4. Examples of problems in biomass production

For the utilization of biomass for industrial and energetic purposes a certain degree of rationalisation and centralisation is necessary to optimize processes and economic outcomes. Intensification of production of biomass generally causes the same disadvantages as intensification of food production. This affects point sources for by-products like smoke (radionuclides), ash, slurry and digestates. Biomass has the disadvantage that it generally occurs in large volumes at low densities. For instance large biogas plants demand huge amounts of biomass that must be transported to them from their source and therefore an adequate traffic infrastructure must be in place (roads, storage, and transport capacity) to facilitate it. Also huge amounts of slurry from biogas plants have to be carried long distances to dump them on arable land or waste dumps. Big portion of water is carried along within fresh biomass to the biogas plant or slurry away from the plant what makes transport over long distances costly. For this reason it is cost effective for some bigger biogas plants to dry down their own slurry and compact and distribute it as pelletized fertilizer. The use of ash from biomass combustion plants as a fertilizer is another possibility for the recirculation of waste to cropping areas.

Potential threats caused by biomass production for energy on the production site include for instance:

- Monoculture landscapes, e.g. corn, sorghum, short coppice plantations, oil palm
- Development of industrial infrastructures in the countryside
- Biomass production on marginal lands such as drained organic soils with all the interrelated problems (see below)
- Nutrient losses to groundwater because of high fertilization and mineralization processes.

5. Nature protection and ethical implications of biomass for energy

In Germany the nature protection and ethical dimensions of increasing biomass production for the non-food sector is a controversial issue [12]. The main problem identified by bio-energy propagators from industrialized countries is the demand to replace fossil fuels with bio-energy, without any changes in total consumption. It seems to be obvious that on one hand the biomass production is competing for land area with the production of comestible goods while on the other hand it ignores the increasing land area demanded by organic farming (in Germany: bio-farming).

Mislead by the “bio” part of “bio”-energy many consumers seem to see their demand for energy supply by sustainable agriculture satisfied. In this case production of renewables is mixed up with sustainable production. In contrast, ethicists claim, for example, that biomass should only be used for the most effective pathways like small scale direct burning instead of liquid fuels (compare table 1); for imports from abroad they demand the adoption of transparent certification standards and prefer to use biomass from landscape maintenance, slurry and waste products. Furthermore, they demand consideration of “good agricultural practices”, keeping to the rule of at least three field crop rotations and more organic farming. In addition, primary forests should be spared, protected areas respected and organic soils not be drained for biomass production [12].

The Royal Society for the Protection of Birds (RSPB) [13] and other European NGOs call for bio-fuels that really work for the climate. This means minimum GHG emission standards to be required by law for all bio-fuels that are sold in the UK and Europe. Schleyer et al. [14] would prefer a multifunctional approach in agriculture to mitigate climate change which considers the reduction of greenhouse gas emissions caused by agriculture itself in combination with other ecosystem services such as the production of clean ground water, maintaining biodiversity, and biomass production which includes the development of innovative new technologies.

The German Ferderal Agency for Nature Consevation (BfN) refers to the German constitutional law: “Mindful also of its responsibility towards future generations, the state shall protect the natural foundations of life and animals by legislation…” (German Basic Law, article 20A)[1]. Strong words of course when regarding bio-energy production? However, these basic rights seem to be threatened by e.g. the deforestation of pristine rainforests for the production of liquid fuels for the world market. But BfN sees several options for an arrangement of bio-energy production in harmony with nature protection and landscape maintenance, e.g. favouring permanent crops over intensively fertilized annual crops [15].

6. Case study for organic soils

The problems and opportunities of bio-energy production can be well shown for peat soils which are soils with organic layers >30cm. In Germany these soils are normally intensively drained to create pastures and meadows. The biomass produced by them is harvested and used for hay or silage making; the latter either as fodder for dairy cows or for supplying biogas plants.

6.1 Problems of the use of peatlands

The drainage of these sites causes GHG emissions of more than 25 tons CO_2 equivalents per hectare per year. The emissions are even higher if the organic peat soils are ploughed e.g. for corn production. Biogas production using corn grown on peatlands causes GHG emissions of more than 600 tons CO_2 equivalents per Terajoule electrical energy whereas direct use of light oil would only produce 75 t CO_2 equivalents per Terajoule [16]. And this absurdity is financially supported by all instruments that are available for “bio”-energy production, including the EEG, EU subsidies etc. (see above).

[1] https://www.btg-bestellservice.de/pdf/80201000.pdf

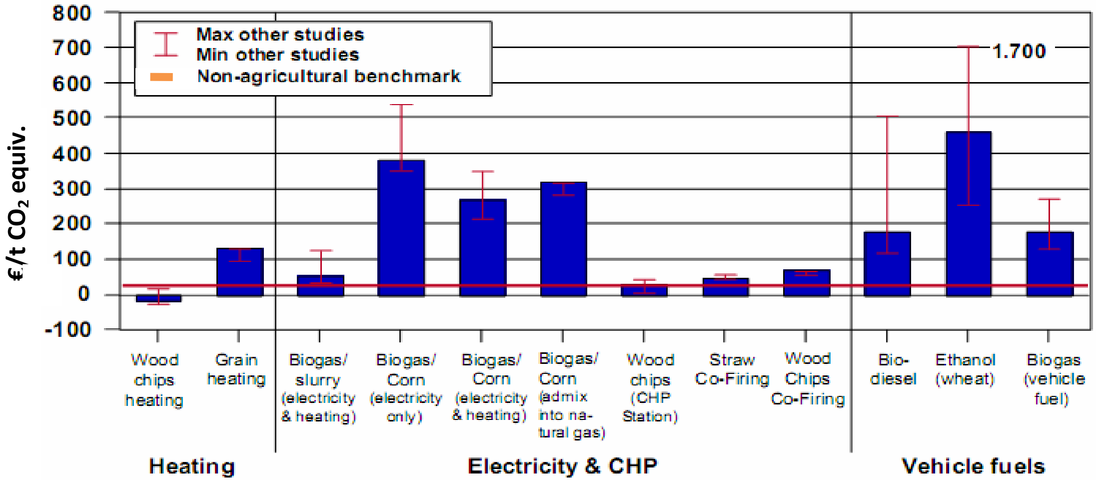

Figure 1. CO_2 mitigation costs, – horizontal line marks non-agricultural benchmark (20 – 30 €/t) [9,11].

Natural functions of peatlands within the landscape like regulation of water quality and quantity, climate regulation (e.g. carbon cycling), nutrient cycling, habitat function (biodiversity), as well as cultural functions should be achievable even if the production function (e.g. provision of food and raw materials) moves into the foreground through land use intensification. This implicates the question as to whether ecologically sound and site adapted bio-energy production on peatlands is possible.

6.2 Paludiculture

In contrast to drainage based agriculture or forestry on organic soils paludiculture (Latin '*palus*' = swamp) is the cultivation of biomass on wet and re-wetted peatlands. In paludiculture such plants are cultivated and harvested that thrive under wet conditions, produce biomass of sufficient quantity and quality, and contribute to peat formation [17].

6.2.1 Assessment of sustainability

The following assesses how far paludiculture complies with the above mentioned principles for sustainable biomass production during production and processing:

1) *Greenhouse gas and carbon balance:* An example of the positive climatic effect of paludiculture is the cultivation of the common reed (*Phragmites australis*) on re-wetted peatland. Such re-wetting results in a GHG emission reduction of some 15 t CO_2-eq·per hectare per year by significantly reducing the mineralisation of peat. With a conservative yield of 12 t DM per hectare per year and a heating value of 17.5 MJ per kg DM the reeds of one hectare can replace fossil fuels in a CHP plant that would otherwise emit 15 t CO_2-eq. Assuming that GHG emissions from handling (mowing, transport, storage, delivery and operation of the cogeneration plant) amount to 2 t CO_2-eq per hectare [19], using reed biomass from paludiculture would thus avoid emissions of almost 30 t CO_2-eq per hectare per year·[17,19]. Both, the emissions reduction from the site by the re-wetting measures, plus the replacement of fossil fuel, add up to about 30 t CO_2-eq per hectare per year, a figure much higher than for any other bio-energy production. Ideally the peatlands should be so wet that peat is conserved and new peat accumulation occurs. In the temperate, subtropical and tropical zones, i.e. those zones of the world where plant productivity is high, peat is formed from the roots and rhizomes of plants growing on wetlands and the vegetation above ground can be harvested without harming peat formation [17].

2) *Food supply and local biomass applications:* Peatlands, at least in Germany, are marginal lands. The productivity and quality of fodder produced cannot keep up with the increasing quality needs of dairy cows caused by increased milk yield per cow. These peatlands are often abandoned or only managed because this is required to get EU-subsidies.

3) *Protected or vulnerable biodiversity:* Re-wetting of drained peatlands is generally beneficial for nature conservation as drained, heavily degraded peatlands are biodiversity deserts. After re-wetting often highly productive but species-poor vegetation develops, providing habitat for rare species such as bittern (*Botaurus stellaris*) and other typical species of reed beds. Biodiversity benefits obtained from paludiculture depend on the management regime of the re-wetted sites (e.g. date of mowing). A famous example is the Aquatic Warbler (*Acrocephalus paludicola*), a fen mire flagship species, and the only globally threatened passerine species of continental Europe which can benefit from paudiculture. The species' natural habitat is in low productive fen mires with permanently high water levels which are dependent on regular mowing in late summer to maintain the open, sparse vegetation the species requires [18]. But biomass use may also conflict with nature conservation, e.g. when early mowing for biogas production destroys breeding habitats or when winter harvesting leaves insufficient old-growth reed. To prevent possible conflicts agro-environmental schemes could be formulated which offer compensation for farmers. In case of areas designated as conservation sites, paludiculture must be considered as a cost-effective management option, instrumental but ancillary to conservation [17]. Monitoring of species after re-wetting is important for further management modifications.

4) *Soil, ground- and surface waters, and air quality: During biomass production on-site*: Re-wetting as a precondition for paludiculture leads to a basic restoration of the site. Soils swell back during re-wetting and the degraded peatland sites, in the long term, can develop again into mires and therefore peat forming ecosystems. The peatlands again function as a sink for carbon as well as for agents dissolved in waters used for re-wetting. Such peatlands could also serve as water filters after waste water treatment. Atmospheric deposits are bound by biomass or fixated in the newly formed peat.

During processing of biomass: During conversion processes e.g. in the heat and power plant potential gaseous and dusty air pollutants can be produced. It is a solvable technical challenge to reduce these contaminants from the exhaust fumes by optimised combustion processes and e.g. electrostatic filtration.

5) *Contribution towards local prosperity and the social well-being of the employees and the local population:* Paludiculture facilitates deriving income from primary production where previously a subsidy oriented management of environmentally critical land use of drained peatlands took place. Autumn or winter harvest lead to more consistent employment throughout the year and additionally working places could be generated,

dependent on the intensity of processing and creation of net added value. In comparison with other bio-energy options (fig. 1) for CO_2 mitigation the wet management of peatlands is connected with minor mitigation costs if the paludiculture production of biomass is done to more or less cover costs. A methodology has been developed and adopted for the offsetting of CO_2 -emissions called Peatland Re-wetting and Conservation (PRC)[2], under the Voluntary Carbon Standard (VCS). Selling carbon credits can provide income in addition to the earnings from the biomass production for energy. A methodology to accredit emissions reductions by the utilisation of biomass from paludiculture is under development as part of a project of the Michael Succow Foundation, sponsored under EU-AID in Belarus called "wetland energy".[3]

6.2.2 Opportunities of bio-energy from re-wetted peatlands

The production of biomass for energy in re-wetted peatlands allows an integration of conservation and agricultural/ forestry use by environmental friendly management of the sites. Paludiculture seems to be an effective and cost-efficient option for the reduction of GHG emissions with several positive effects on the environment. Switching from drainage based peatland management to paludiculture is additionally an optimal strategy for adaptation to climate change by regional cooling effects caused by high transpiration from vegetation and soil.

7. Conclusions

For biomass production, as for any other business, basic principles of sustainability should be followed. For transition periods exceptions may be acceptable. At least during the times of introduction of new production chains the economy may be dependent on subsidies such that initial uncertainties of production and an initial lack of efficiency can be buffered.

The consumption of land and the competition for productive soils that could also be used for the production of comestible goods will remain a crucial problem of biomass production. This can be avoided by concentrating biomass production on degraded lands or by switching to the use of waste and by-products of agricultural production. The challenge is to find the best and most sustainable mix of alternatives.

The use of biomass fuels from drained peat soils perversely results in higher emissions than using fossil fuels. Drained peatlands should therefore not be stocked with biomass energy crops, but re-wetted and used for paludiculture. The paludiculture example shows that it is possible to meet most basic principles of sustainability as it:

- preserves the peat layer and allows new peat accumulation
- decreases GHG emissions from the peat soil
- allows the production of "clean" biomass that doesn´t need to compete with food production
- restores and maintains habitats for rare and threatened species, and
- gives opportunities for employment in rural areas.

This positive example shows that there is a wide slot available for sustainable biomass production if the principles of sustainability are considered.

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