SUSTAINABILITY OF BIOENERGY PRODUCTION FROM GRASSLAND – CONCEPT, INDICATORS AND RESULTS

Christine Rösch[1], Konrad Raab[2], Johannes Skarka[1], Volker Stelzer[1]
[1]Research Centre Karlsruhe, Institute for Technology Assessment and Systems Analysis (ITAS)
P.O. Box 3640, 76021 Karlsruhe, Germany
[2]Ministry of economics Baden-Württemberg, Stuttgart, Germany

ABSTRACT: In Germany, the demand for biomass to produce renewable energy is raising due to political sustainability goals and financial measures to support bioenergy. While the disposable arable land for the cultivation of energy plants is limited, increasing interest is put on grassland which is no longer needed for dairy cattle production. Since there are different types of "surplus" grassland and because grass can be used either to produce solid biofuels or biogas, the impacts of different technologies have been analysed against the background of sustainable development. The objective of the work is to provide information to support socio-political decision processes with respect to a sustainable development of the bioenergy production from grassland. The conclusion of the analysis is, that the different technologies to gain energy from grassland have positive, but also some negative impacts on ecological aspects of sustainability. On the one side the utilization of grass as feedstock leads to savings in non renewable energy and to reductions of greenhouse gas emissions and can contribute to the protection of soil and groundwater and to the preservation of biodiversity and cultural landscape. On the other side there are also negative impacts on sustainable development such as the increase of emissions leading to acidification, eutrophication and risks for human health. Despite relatively high energy prices and the financial support for the energetic use of biomass, the effects of bioenergy production from grassland on employment and wage compensation in agriculture – representing the socio-economic indicators of sustainable development in this analysis – are modest, respectively if the biomass is used to satisfy the energy demand of the farm or is sold on the market as feedstock for bioenergy plants.

Keywords: sustainable use of biomass, life-cycle assessment, grassland

1 INTRODUCTION

Almost 30 % of the agricultural area in Germany is permanent grassland and thus grassland forms a substantial part of cultural landscape in some regions of Germany. Meadows and pastures contribute to nature and environmental protection, tourism and regional economy. Hence there is strong interest to stop the decline of grassland through conversion to arable land or afforestation. Consequently, one result of the agricultural reform in Germany is that area-based payment entitlements are now also paid for grassland. These premiums will rise to around 300 €/ha by the year 2013. Furthermore the conversion of grassland is limited by law to not more than 5 % of the existing permanent grassland (compared to 2003). If more than 8 % of the grassland will be converted, reseeding of grassland can be instructed [1].

Producing roughage for feeding dairy cattle is the most important use for permanent grassland in Germany. However, an increasing part of the grassland is not needed anymore for this purpose. This is due to progress in breeding and production technology and to structural adjustments in agriculture. In some regions of Germany almost one quarter of the grassland is without utilization in animal husbandry [2]. Against this background and with regard to the rising demand of biomass feedstock for energy plants in Germany this "surplus" grassland could be used as "green" resource to produce bioenergy.

For the conversion of grass into effective energy either hay bales or pellets can be used as solid biofuels for small combustion units or grass silage can be produced as co-substrate (in mixture with manure and maize silage) for biogas plants. Of these two grass utilization paths, today the conversion of grass into biogas used for electricity production is quite attractive due to the availability of proven conversion technique on the market and the financial support by the Renewable Energy Sources Act [3]. This act forces power supply companies to take over electricity from biomass and other renewable sources and to pay guaranteed minimum prices for it. In order to promote the extension of bioenergy production, an additional bonus is paid for the conversion of biomass into electricity. Thus it is not amazing, that in Germany the number of biogas plants has increased rapidly up to now 3,300 [4]. The installed electrical power of these plants amount to 5.4 TWh_{el} requiring 55 PJ feedstock per year. This demand corresponds to an agricultural area of 400,000 to 500,000 ha. After maize silage, which represents approximately 80 % of the agricultural biomass for biogas plants, grass silage is the most important biogas feedstock [4].

Since there are different types of grassland and because grass can be used either to produce biogas or solid biofuels for combustion processes, the Institute for Technology Assessment and Systems Analysis (ITAS) has analysed the impacts of different technologies to use grassland for the production of bioenergy under the view of sustainable development. The purpose of the work is to provide a broad basis of information to support socio-political decision making processes with respect to the development of a sustainable bioenergy production from grassland. In this paper, the concept and indicators applied for the sustainability assessment of bioenergy production from grassland as well as results of this sustainability analysis are presented.

2 APPROACH

The starting point of the work is the so-called integrative concept of sustainable development which was elaborated in ITAS as a conceptual and analytical framework for sustainability analyses. This global concept was adapted to the object of investigation in order to meet the relevant sustainability aspects related with bioenergy production from grassland. A set of core indicators was selected to ensure analytical practicability, and to meet the requirements of the specific characteristics of the evaluated process chains. The criteria used for the selection of indicators were the adequate reproduction of the core ideas of the rules, the possibility to set quantitative goals or to recognise the direction of increasing and decreasing sustainability, and finally the availability of suitable data.

2.1 Preconditions and indicators of sustainability

Through the adaptation of the integrative concept of sustainable development on the scientific questions of the project the number of relevant preconditions of sustainable development was reduced from fifteen to seven substantial sustainability goals (see Table 1). To operate these sustainability targets in the context of bioenergy production from grassland eighteen indicators have been chosen.

Table 1: Preconditions of sustainable development and selected indicators

PRECONDITIONS OF SUSTAINABLE DEVELOPMENT	INDICATORS SELECTED
Just distribution of chances for using the environment	• Substitution of non renewable energy resources • Emissions of greenhouse gases
Sustainable use of non renewable resources	• Substitution of non renewable energy resources • Primary energy yield • Emissions of greenhouse gases
Sustainable use of the environment as a sink	• Emissions of greenhouse gases • Greenhouse gas reduction costs • Emissions affecting eutrophication • Emissions affecting acidification
Protection of human health	• Emissions of fine dust • Emissions of NO_x • Emissions of CO • Emissions of substances producing summer smog • Development of fungus spores
Sustainable use of renewable resources	• Biodiversity • Soil • Ground and surface water
Conservation of the cultural functions of nature	• Nature of the landscape
Autonomous subsistence based on income from own work	• Employment • Wage compensation

For the selected indicators quantitative goals were formulated. These were either adopted – in cases of already existing political decisions – or chosen in view of actual debates or developed independently within the project. Based on this set of respective goals and indicators, the sustainability of different technologies to use grassland as an energy resource was analysed.

As reference for the evaluation of the investigated techniques the maintenance of the grassland through mulching and the production of heat and electricity with fossil fuels were chosen.

2.2 Definition of bioenergy production chains

In the evaluation process nine different techniques for the conversion of biomass from grassland into effective energy have been analysed. Hereby the technologies have been distinguished between those usable to convert grass from intensively and others to apply grass from extensively used grassland. With regard to the quality of the grass harvested, for extensive grassland the production of hay bales or pellets and the application in small combustion units have been taken into consideration. Furthermore, the use of hay (together with maize) as substrate for a dry fermentation biogas process has been investigated. For intensive grassland, the production of grass silage as feedstock for biogas plants with conventional wet fermentation process was assumed.

Due to the fact that to a certain limit the conversion of grassland into arable land is still possible also two bioenergy generation chains based on converted grassland have been analysed: the production of maize silage for biogas plants (only on intensive grassland) and the plantation of short rotation poplars (on intensive as well as on extensive grassland, but with different yields).

2.3 Life-cycle analysis

The impacts of the different technologies have been analysed for eleven of the eighteen indicators by means of the Global Emission Model for Integrated Systems (GEMIS) Version 4.3. This is a life-cycle analysis program and database for energy, material, and transport systems, which is freely available as public domain software. GEMIS includes the total life-cycle in its calculation of impacts – i.e. fuel delivery, materials used for construction, waste treatment, and transports and auxiliaries. With this module relevant stock and energy flows of the different technologies have been computed. Results calculated with GEMIS are related to energy efficiency, direct air pollutants (SO_2, NO_x, halogens, particulates, CO, NMVOC) and greenhouse gas emissions (CO_2, CH_4, N_2O, CF_4, C_2F_6).

3 RESULTS

According to the availability of data and methods to aggregate singular emissions to impact dimensions, the sustainability analysis includes different types of results: quantitative emissions or impact results computed with the life-cycle analysis program and qualitative evaluations based on literature analysis. As result, there are for each bioenergy technology both positive and negative impacts on different indicators. As up to now there is no scientific concept available for a further aggregation of impacts on different sustainability indicators and because for a ranking of sustainability goals consensus in society and politics is needed, subsequent the impact analysis is presented in single results.

3.1 Savings of non renewable energy and reductions in greenhouse gas emissions

The analysed bioenergy chains – grass silage form intensive grassland, different hay bales and hay pellets from extensive grassland as well as maize silage and short rotation poplar chips from converted intensive grassland – show significant benefits in savings of non renewable energy resources and in the reduction of greenhouse gas emissions. The highest area-specific net savings can be achieved with the conversion of intensive grassland into short rotation poplars (see Figure 1). Besides, on the level of present oil prices short rotation poplars grown on converted intensive grassland can achieve negative costs for the avoidance of CO_2 emissions (see Figure 2).

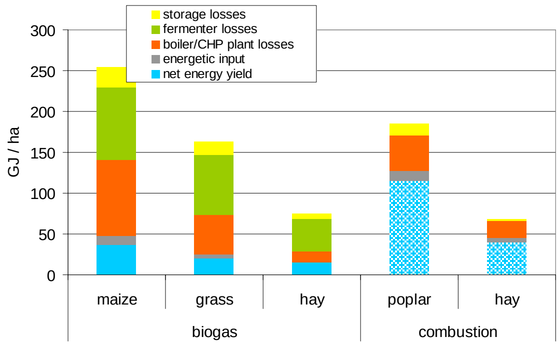

Figure 1: Energy yield per hectare of techniques to gain energy from intensively and extensively used or converted grassland

Although there is a great difference regarding the yield of extensively or intensively used grassland, similar savings of non renewable energy can be achieved with both utilization paths. This is due to the fact, that the heat generated by the production of electricity from biogas can mostly not be used and thus an important part of the produced bioenergy from grassland gets lost. Additionally, the energy losses by the conversion of grass silage using biogas fermenter are higher than those occurring by the direct energy conversion through the combustion of hay. However, the ranking changes if a significant part of the heat produced from biogas can be reasonably used. In this case, the relatively high costs to avoid greenhouse gas emissions by the energy production from grass silage can be reduced from around 250 €/t CO_2 equivalent to 175 €/t CO_2 equivalent (see Figure 2).

The costs for avoiding greenhouse gas emissions are much lower if hay from extensive grassland is used to produce thermal energy. They range from 70 to 80 €/t CO_2 equivalent for hay bales or pellets. But even the use of hay as solid biofuel is at present not competitive compared to the average price for EU certificates for CO_2 emissions ranging in 2006 on average around 18 €/t CO_2 equivalent.

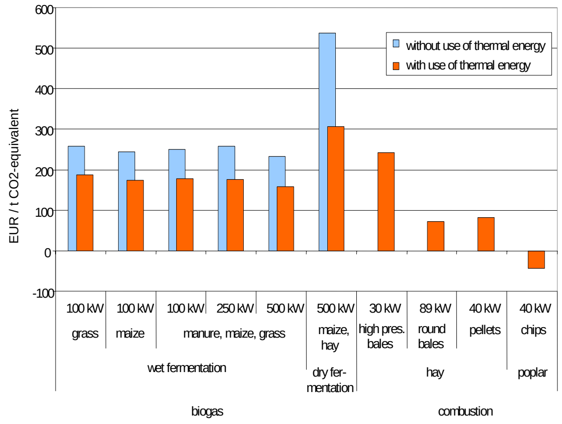

Figure 2: Greenhouse gas emission reduction costs of techniques to gain energy from intensively and extensively used or converted grassland

3.2 Emissions leading to acidification, eutrophication and risks for human health

In the field of acidification and eutrophication all techniques analysed are related with higher emissions than the reference mulching and energy generation by fossil energy technologies, respectively the biogas techniques. Only short rotation poplars show relatively good results. Concerning the emissions of substances stressing human health, such as NO_x and CO, the evaluation of all techniques analysed is negative compared to the reference. The additional burden of fine dust emissions is respectively high regarding the techniques combusting hay or short rotation poplar chips (see Figure 3). However, the fine dust emission loads can be reduced significantly by using retention techniques.

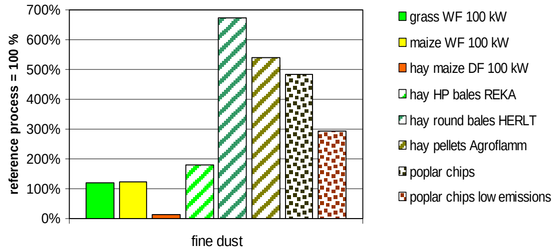

Figure 3: Emissions of fine dust of techniques to gain energy from intensively and extensively used or converted grassland

3.3 Protection of soil and groundwater

With respect to the protection of soil from erosion and compaction, the techniques using grassland as energy resource show much better results than converting grassland into arable land for the production of maize as feedstock for biogas plants. Furthermore, grassland plays a major role in groundwater protection, because the discharge of substances emanating from the use of fertilisers and pesticides towards groundwater is very low under grassland compared to arable land. Grassland shows on average a low degree of nitrate and pesticides leaching similar to those under forest. In contrast, the conversion of grassland into maize fields can lead to negative impacts on groundwater quality.

The plantation of short rotation poplars brings along a risk of soil erosion and nitrate leaching towards the groundwater directly after the conversion of grassland. However, over the years short rotation poplars can reach a similar protection function for soil and groundwater quality as grassland and forests.

3.4 Effects on biodiversity

Grassland is an important habitat for different plant and animal species. In relation to biodiversity the utilization of hay as solid biofuel is superior to the reference mulching. However, if the use of extensive grassland is intensified in order to deliver grass silage with a good quality for biogas plants, this can lead to a loss of biodiversity.

The conversion of grassland into maize fields or short rotation poplars causes a significant change in the diversity of species compared to the reference mulching. Thereby the cultivation of maize is significantly reducing the diversity of species. The influence of short rotation poplars on biodiversity is – in dependence of the habitat – less unfavourable. In the literature it is documented that in short rotation poplars new types of biodiversity can be build up including even endangered species [5].

3.5 Effects on the cultural landscape

In some regions of Germany grassland is shaping the cultural landscape and contributes considerably to the peculiarity and attraction as well as to the quality for living and recreation in these areas. This cultural function of grassland is interfered by converting grassland into maize fields. To a similar result leads the plantation of short rotation poplars supplemented by the loss of open or semi-open cultivated landscape. In areas with an already high percentage of forest this will have mainly negative consequences for the living and recreation quality as well as for tourism in this region [6, 7]. In such cases a rejection of short rotation plantations by the population can be assumed. Whereas also positive impacts of short rotation plantations are feasible in areas which are used intensively for agricultural production and possess only a small percentage of trees and groves [8].

3.6 Effects on employment and wage compensation

Ranking the analysed techniques with regard to socio-economic aspects of sustainable development is a quite difficult task because of two reasons: First, there is no concept or agreement which sustainability goals or indicators should be taken for evaluating the socio-economic sustainability of agriculture. Second, the information background on impacts of bioenergy production on socio-economic aspects is rather small. Therefore the analyses done in this study concentrate on effects on working time and wage compensation on the farm level. Looking at these two indicators it can be concluded that – with the exception of producing poplar chips for the market – the demand of labour time is much higher than in the reference (see Figure 4). However, compared to the traditional use of grassland for roughage and milk production less working hours are required for the bioenergy production from grassland.

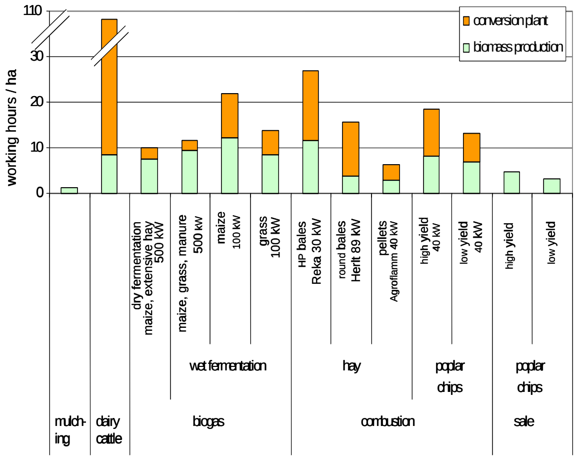

Figure 4: Demand of working hours of techniques to gain energy from intensively and extensively used or converted grassland

Regarding the wages, some techniques to produce energy from grassland are leading to wage compensations between 6 and 50 € per working hour (see Figure 5). However, the production of high pressure hay bales, hay pellets and poplar chips for the market can lead to negative wage compensation.

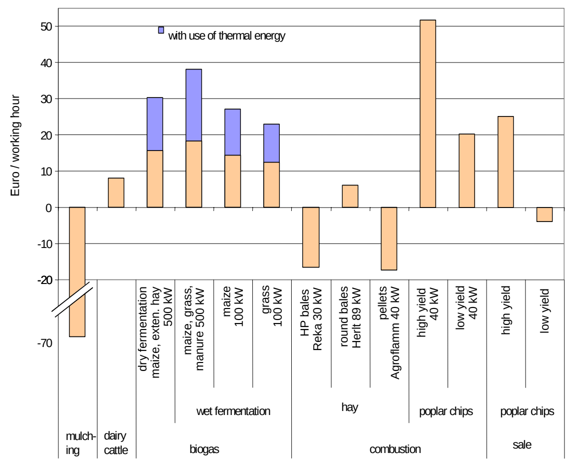

Figure 5: Wage compensation of techniques to gain energy from intensively and extensively used or converted grassland

Despite the relatively high wage compensation, the production of thermal energy by the combustion of poplar chips or hay on the farm does lead only to a limited income. This is due to the fact, that only a small area of land is needed to cover the average heat demand of a farm. Using poplar chips, for example, only between 2 and 6 hectares short rotation coppice are required. Despite relatively high energy prices and the financial support for the energetic use of biomass, the effects on wage compensation and employment in agriculture – representing the socio-economic indicators of sustainable development in this analysis – are modest, respectively if the biomass is used to satisfy the energy demand of the farm or if the biomass is sold on the market as feedstock for bioenergy plants.

4 CONCLUSIONS

The evaluation of techniques to produce energy from grassland under the view of sustainable development reveals that the technologies analysed have both advantages and disadvantages. The use of grass for the production of biogas – which is practised already in Germany – as well as the combustion of hay can reach the threshold of profitableness if the guaranteed agricultural premiums are included in the calculation. However, not at every location and in all cases the technologies can be operated economical. Besides, all technologies achieve effects on employment which are high compared to mulching, but low compared to dairy cattle production.

Concerning the reduction of greenhouse gas emissions only short rotation poplars on good locations can reach reduction costs which are compatible with current costs for EU emission certificates for CO_2. The other technologies result in relatively high greenhouse gas reduction costs. These costs would be even higher if retention techniques to avoid emissions of fine dust and other environmental harmful substances would be applied. Thus, research is needed to improve the existing techniques and the knowledge for bioenergy production from different types of grassland with the intention to augment the benefits (e.g. through a more efficient use of grass as bioenergy feedstock) and to decrease the accompanying disadvantages for the environment and human health. In case of using grass silage for biogas plants one way to achieve these goals is to create financial incentives for using biogas at locations with a high demand of thermal energy or to feed biogas into the natural gas distribution grid.

The production of short rotation poplars on converted grassland presents a surprisingly good sustainability performance, respectively if the emphasis is put on savings of non renewable energy and reduction of greenhouse gas emissions. However, if importance is attached to the conservation of grassland with regard to biodiversity and cultural landscape, on extensive grassland the combustion of hay – preferable with fine dust retention measures – would be the preferable choice from the view of sustainability.

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