ENERGY CROPS AND SUSTAINABILITY – DEVELOPMENT OF AN EVALUATION MODEL

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Abstract. *Demand for bioenergy crops from arable land is likely to increase in the future, and there is a need to verify their sustainability. In sustainability assessment many different factors must be considered, including social, economic and ecological/environmental aspects. We have developed a model to evaluate the sustainability of bioenergy crop cultivation. The focus of this study was to illustrate and evaluate the model's usefulness. The model was therefore developed only to a limited extent where a few criteria are selected and only willow cultivation in Götaland northern plains in Sweden is evaluated. The model is aimed for local authorities, to function as decision support. The model evaluates the greenhouse gas emissions, energy balance, nitrogen leaching together and the impact on the landscape. For the impact on the landscape a scoring system was developed to make it quantifiable and thus possible to evaluate along with the other criteria. The model was tested in a case study on a willow cultivation, with winter wheat and ley as reference crops. The model proved to be a good basis for evaluation of sustainability in the cultivation of energy crops. The graphical presentation of the model result clearly showed how the different crops perform in the included criteria. We however conclude that the model needs to be extended and refined before it can function as a basis for choice between different crops or location sites.*

Key words: *Bioenergy, willow, sustainability, model, landscape.*

INTRODUCTION

Demand for bioenergy crops from arable land is likely to increase in the future. Energy crops should contribute to sustainable development. In sustainability assessment many different factors must be considered, including social, economic and ecological/environmental aspects.
In this project, we have developed a model that can be used to quantify and graphically visualize different aspects of sustainability when cultivating energy crops. The focus of this initial project was to illustrate and evaluate the model's usefulness. The model is therefore developed only to a limited extent where a few criteria are selected and only willow cultivation in Götalands norra slättbygder (Götaland northern plains) is evaluated. The model is aimed for local authorities, to function as decision support. In cooperation with a reference group, four sustainability criteria were selected; (1) greenhouse gases, (2) nitrogen leaching, (3) energy balance and (4) impact on the visual landscape character. The model was tested in a case study, comparing willow with two reference crops, winter wheat and cultivated grassland (ley).

MATERIALS AND METHODS

The first three criteria are quantifiable and were calculated using life cycle assessment methodology. The system boundary is at the field edge, which means that the use of the crop is not included. For greenhouse gases, emissions of carbon dioxide, methane and nitrous oxides were included from all processes upstream (e.g. production of fertilizers) and from the field based on data in [1]. The energy balance was calculated as the ratio between primary energy input and higher heating value energy content in the produced crop. For nitrogen leaching, average data from Johansson and Mårtensson [2] was used, which is data based on modelling of leaching for different crop and soil types, combined with statistics on yields, nitrogen fertilization levels as well as weather data. For further explanation of input data, see Gunnarsson et al. [3].
The fourth criteria, impact on the visual landscape, which by the reference group was judged to be a key issue to address if an expansion of willow cultivation is to take place, is more difficult to quantify, and a framework for the evaluation needed to be developed. The new framework is based on Lynch [4] who was a pioneer in evaluation of city landscape structures. The framework we have developed consists of five questions that focus on visual impact, where each question is assessed according to the scale small impact (1 point), medium impact

(2 points) and large impact (3 points). The questions include field size, impact on landscape topography, impact on paths in the landscape, impact on individual elements and impacts on scenery and horizons. The reference crops wheat and ley were assumed to have small impact on the visual landscape, and given the highest (most positive) score.

The four selected criteria were normalizing according to min-max methodology on a scale between 0 and 1, where 1 is the best value and 0 the worst value. The best and worst value for each criterion was selected based on the best and worst crop in the region, which were different crops for each criterion. Impacts of the selected criteria for all crops in the region were based on same methodology as described above, and regional statistics.

RESULTS AND DISCUSSION

The model was tested in a case study on a willow cultivation in the northern plains of Götaland (Figure 1). The willow field is 3 hectares, fertilized with sewage sludge and mineral nitrogen, with a yield of 12 500 kg dry matter per hectare and year. The soil type is clay loam. As a reference, cultivation of ley and winter wheat on the same field was also put into the model.

Figure 1. **Overview of the case study area in the northern plains of Götaland**

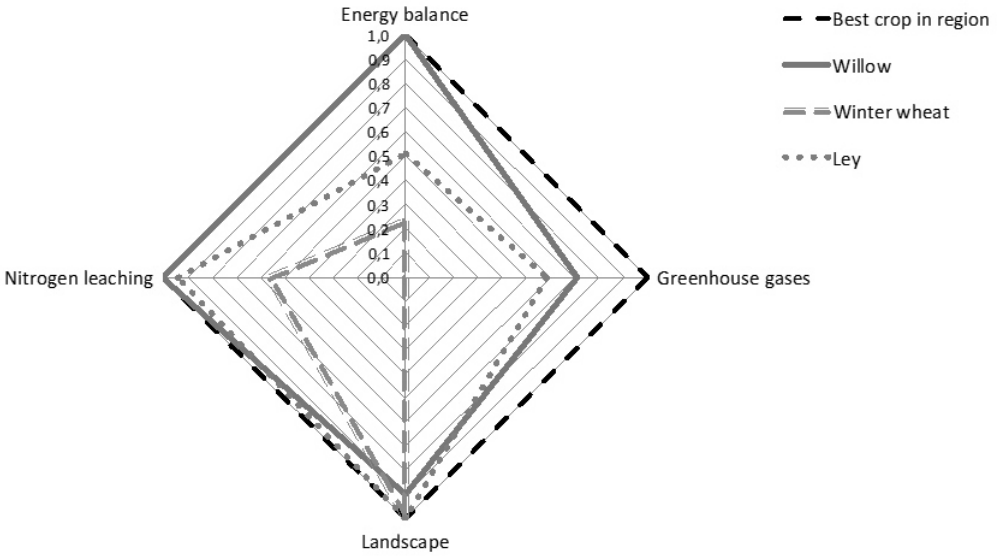

Figure 2. **Case study model results for willow, winter wheat and ley cultivated on a field in the northern region plains of Götaland in Sweden, impact per hectare for different criteria. Maximum score (best crop in region)=1, minimum score (worst crop in region)=0.**

In the case study, willow turned out better than the reference crops for the criteria energy balance, greenhouse gas emissions and nitrogen leaching, but willow had worse results for the landscape criteria (Figure 2). Preference of one crop over the other may of course depend on the choice of criteria, had other criteria been selected the assessment could have another outcome.

Willow gets worse results for the greenhouse gas criteria than one might have anticipated; this is due to emissions from the production of nitrogen fertilizers and emissions of nitrous oxide from soil. This result is when we calculate per hectare. As the willow has a relatively high yield, the results would be different if calculated per kg of crop. Winter wheat gets poor results, especially for greenhouse gases, it is one of the worst crops to grow on this field according to the model since it has high application rates of nitrogen fertilizers.

Impact on the landscape is relatively small in all cases, which may be due to the case study farm being a plain where the field is the same size as the surrounding fields and that no specific paths, views or horizontal lines are affected. The good results could also be an outcome of the developed method and there is a need to adjust and validate the model by testing it on other cultivation sites.

For the energy balance, the studied willow field scored best of all crops in the northern region plains of Götaland, due to the high yield and low energy input. The reference crops ley and winter wheat had an average or lower score compared to willow.

The nitrogen leaching was lowest (had the highest score) for willow, closely followed by ley. Winter wheat ha a much higher nitrogen leaching, but lower than the worst crop (spring barley) in the northern region plains of Götaland.

CONCLUSIONS

The model developed in this project evaluates the quantitative criteria greenhouse gas emissions, energy balance and nitrogen leaching together with the qualitative criterion impact on the landscape. For the impact on the landscape a scoring system was developed to make it quantifiable and thus possible to evaluate along with the other criteria. The model proved to be a good basis for evaluation of sustainability in the cultivation of energy crops. The graphical presentation of the model result clearly showed how the different crops perform in the included criteria.

Should the model be developed so that more criteria, cultivation areas and energy crops are included, the model could serve as a basis for selection of crops or choice of cultivation site. For development of an overall assessment, economy and biodiversity would be relevant sustainability criteria to include. Farmers and farm advisors could then be both users of the model and the model results.

As with all crop models, the results were found to be sensitive to different assumptions, for example about the yield and fertilization. The evaluation is also affected if the results are calculated per hectare or per kg crop; crops with high yields generally perform better calculated per kg crop.

Another conclusion from the project is that sustainability assessments are complex, and more development of the model is needed in terms of scope and method to provide a broader and more nuanced picture of the impact on sustainability. The number of criteria as well as the number of energy crops needs to be expanded. The calculation of the individual criteria can be refined, in particular the evaluation of the impact on the landscape. Also the normalization and visualization of the result can be improved.

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