APPLICATION OF A GIS-BIOLOCO TOOL FOR THE DESIGN AND ASSESSMENT OF BIOMASS DELIVERY CHAINS

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ABSTRACT: The spatial fragmentation of different biomass sources in one or more regions makes design and assessment of sustainable biomass delivery chains rather complicated. This paper presents a GIS-BIOLOCO tool that supports the design and facilitates a sustainability assessment of biomass delivery chains at a regional level, in terms of the regional availability of biomass resources, costs, logistics and spatial and environmental implications.
The tool consists of the BIOLOCO model which optimizes the chain to a set of pre-defined economic and Green House Gas (GHG) efficiency targets. The model is linked to a GIS basis, to take account of the detailed spatial pattern (dispersion and concentration) of biomass resources. The combination of BIOLOCO with GIS makes it possible to 1) compute more accurately the expected supply of biomass in a certain region, 2) compute more accurately the transportation distances, related costs and GHG emissions, and 3) to assess the spatial impacts of the feedstock requirements of different chain designs on land use, environment, landscape and biodiversity.
In this paper, two case studies in The Netherlands are assessed using GIS-BIOLOCO; a straw-based bioenergy chain based on current land use and a hypothetic willow-based bio-energy chain based on future land use.
Keywords: biomass production, logistical models, environmental aspects biomass production, geographical information system (GIS)

1 INTRODUCTION

The biomass that is used as feedstock for a conversion unit (e.g. a power plant) is usually spatially dispersed. The spatial fragmentation of different biomass sources complicates the design and assessment of sustainable biomass delivery chains. Additionally, there is a need for this assessment on the regional scale by stakeholders such as regional governmental bodies and companies with an interest in bioenergy. The tool presented in this paper can facilitate the spatial design and assessment of biomass delivery chains on different aspects such as: finances, logistics, energy production and environmental impacts.

The core of the tool is the BIOLOCO logistical optimization model [1,2] which facilitates the making of optimal choices with respect to different components in the biomass supply chain such as biomass type, type of power plant, locations, transport type, storage facilities and pre-treatments methods. Optimization is done by applying different object functions to the potential bioenergy chain. These object functions are already included in the model such as maximization of financial revenues, maximising energy returns, minimization of financial costs and minimization of emissions.

Recently a geographical information system (GIS) basis has been linked to the BIOLOCO model in order to include the detailed spatial pattern (dispersion and concentration) of biomass resources in the optimisation of the chain and afterwards to map the detailed spatial implications on land use to be used as a basis for further environmental and ecological impact assessment. The use of GIS makes it possible to 1) compute more accurately the expected supply of biomass in a certain region, 2) compute more accurately the transportation distances and related costs, and 3) to assess the spatial impacts of the feedstock subtraction of different chain designs on land use, environment, landscape and biodiversity.

Thus, with the GIS basis, better choices can be made in terms of which part of the biomass resources can be used in a sustainable way and what the spatial implications are of using them. Once the feedstock mix has been defined and the exact delivery points have been chosen, then the environmental effects of biomass removal and cropping can be estimated. Additionally, this enables comparison of different chain designs).

In this paper, the GIS-BIOLOCO tool is applied to two case studies to demonstrate the methodology developed, although the environmental impact assessment of the land use change is not yet included.

2 METHODLOGY

The GIS-BIOLOCO tool consists of five consecutive steps (Fig. 1).

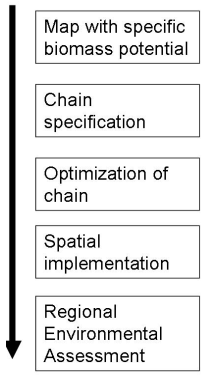

Figure 1: Tool structure of GIS-BIOLOCO

2.1 Maps with specific biomass potential

The first step consists of generating the maps with the potentially available biomass of specific crops or other biomass types. For conventional crops, e.g. wheat or maize, data on the current production quantities and locations can be used. For future crops, e.g. willow or *Miscanthus*, potential biomass maps have to be developed based on assumptions on future shifts in land use and cropping systems. For the GIS-BIOLOCO tool, inputs are needed in terms of maps showing future potential biomass dispersion patterns based on e.g. current land use, Net Present Value calculations (NPVs) and farmer expected response. These type of maps have also been developed for the case-studies presented in this study, but will not be further discussed here.

2.2 Chain specification

The bioenergy chain consists of two parts; the conversion unit and its corresponding supply network. The conversion unit (power plant) is characterized in three dimensions: economically, required biomass type and required biomass quantity. These three dimensions are quantified by several variables, e.g. type of energy produced, the conversion technology, the size of the conversion unit, the expected amount of imported biomass, the investments costs for the conversion units has to specified, and the price per energy unit.

The network consists of the following location categories: biomass sources, collection points and conversion units (Fig. 2).

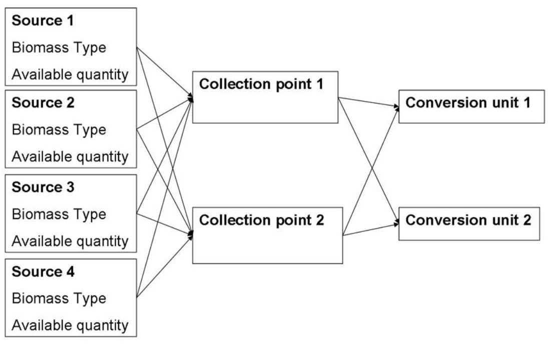

Figure 2: Network structure GIS-BIOLOCO.

Based on a regional biomass supply map, a grid structure is applied to the map, where the different Sources each relate to a specific grid cell (in the presented case studies, one cell is 15x15 km). For each Source, the amount of biomass per biomass type, the purchase price and the distance to Collection Points and Conversion Units are generated. Pre-treatment of the biomass (e.g. wood-chipping) can take place in any of the three location categories.

2.3 Optimization of chain

GIS-BIOLOCO can optimize on different aspects of the chain, i.e. economics, logistics, energy production or GHG emissions. The optimization results in a chain and a corresponding feedstock subtraction pattern from the grid cells. It is calculated whether a conversion unit can subtract enough biomass to be profitable. Additionally, it is calculated what the optimum feedstock substraction pattern is in terms of biomass type, amount and transport distance.

2.4 Spatial implementation

When the feedstock substraction patterns of the conversion unit(s) are known in terms of amount and type of biomass per grid cell, the biomass allocation pattern within a grid cell has to be determined, after which the specific impact on environment, landscape and biodiversity can be determined. The mapping within a grid cell can be based on a combination of physical conditions and environmental, ecological, landscape and planning constraints. From an economic perspective biomass can either be expected to grow on marginal lands with corresponding low yields, or on the best soils. However, suitable locations may be located in designated Nature areas or in drought sensitive areas and this may not be acceptable from an environmental and/or planning perspective (Fig. 3).

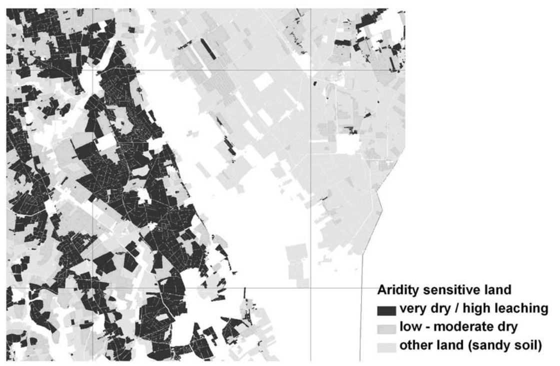

Figure 3: The diversity in drought sensitive areas within one grid cell

Hence, the spatial allocation rules applied within a grid cell will be very determinant for the actual biomass dispersion pattern and thus for the environmental impacts of a bioenergy chain.

2.5 Regional environmental assessment

The regional environmental assessment of the feedstock cropping system will include: GHG-balance for the whole chain including the cropping part and effects on water quality and quantity, soil, landscape and biodiversity. Indicators and models are currently being developed to do these assessments, but will not be further discussed as part of this paper.

3 THE CASE STUDIES

3.1 Biomass to electricity in the North of The Netherlands

Currently, 400.000 ha of arable land exist in the North of The Netherlands, an area with a relatively low population density for national standards. It is the only region in The Netherlands, where bioenergy cropping systems may become profitable.

In the two case studies presented in this paper, the bioenergy chains consisted of two possible locations for a conversion unit (indicated as star in Fig. 4) requiring 30.000 ton dry matter (DM) to produce 110.000 GJ electricity. The optimization target was to maximizing the profit margin of the conversion unit by choosing the best location.

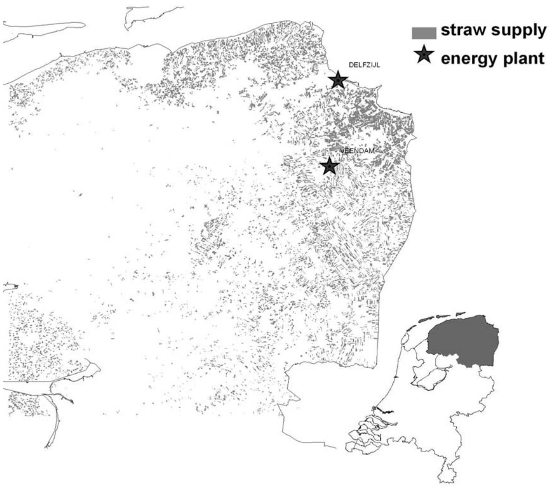

Figure 4: Straw supply per field in the North of the Netherlands.

3.2 Case 1: Straw to electricity

The biomass supply map was based on the straw production of the three most dominant cereals in 2006 (Fig. 5). At this moment straw is partly harvested and sold by farmers to e.g. cattle or horse owners. We assume that a part of this (only 25%) would be available for bioenergy production.

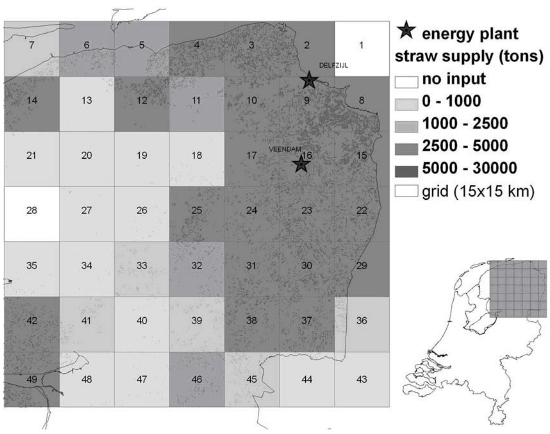

Figure 5: Map of potential straw supply per grid cell.

3.3 Case 2: Willow to electricity.

The biomass supply map of willow was based on the following assumptions. All arable land was included, except areas where currently cash crops (i.e. potato, sugarbeet and vegetables) are grown, also excluding grassland, drought sensitive areas and designated nature areas (Natura 2000). Because of the expected competition for arable land and the reluctance of farmers to change their cropping system, only 10% of the calculated willow biomass potential was assumed to be available for bioenergy (Fig. 6).

These assumptions are fairly crude. More realistic biomass maps are presently developed based on NPV values, farmer behaviour and future scenarios of commodity market developments, but these could not yet be used for this assessment.

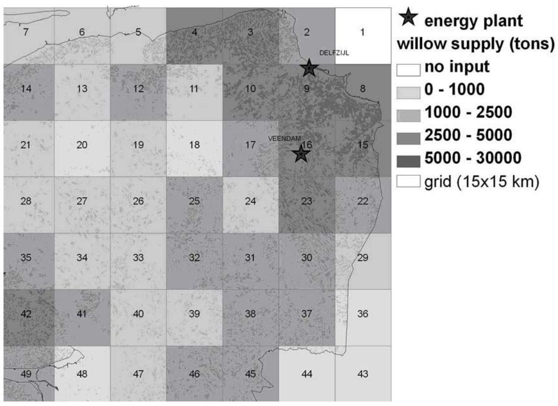

Figure 6: Map of potential straw supply per grid cell.

4 Results

4.1 Case study 1: Straw to electricity

Based on the straw supply map (Fig. 5), GIS-BIOLOCO optimized the chain for the profit margin and generates a straw subtraction pattern as presented in Figure 7.

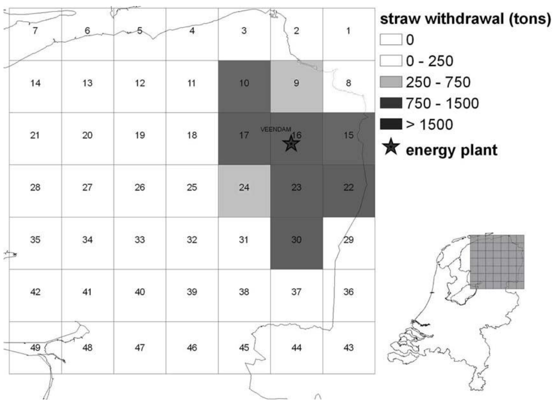

Figure 7: Straw subtraction pattern by conversion unit in Veendam, the Netherlands.

Substraction patterns are based on supply per grid cell, distance and feedstock price. The substraction pattern of the straw to electricity chain is fairly condensed and located in the direct vicinity of one conversion unit that was chosen by the optimization. In competition with this conversion unit, the second conversion unit was not economically viable.

4.2 Case study 2: Willow to electricity

When using willow as feedstock biomass, again only one conversion unit is economically viable. The feedstock subtraction pattern, however, is very different (Fig. 8).

The substraction pattern of the chain includes more grid cells, resulting in an increased transport distance in comparison to the straw substraction pattern. This results in higher transport costs as compared to straw feedstock (Tab.I) and related higher GHG emissions. The time window for willow harvest lasts longer than for straw, and therefore storage costs can be partly avoided.

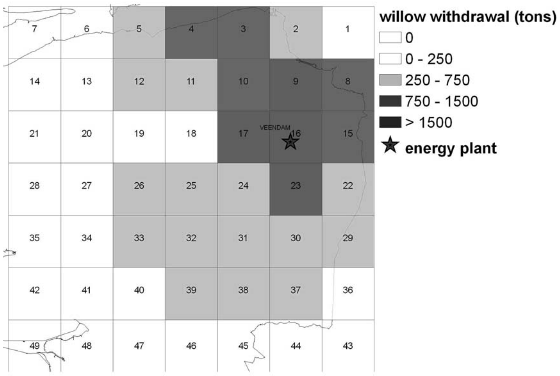

Figure 8: Willow subtraction pattern by conversion unit in Veendam

4.3 Comparing bioenergy chains

The difference in transport costs is caused by the fact that straw is collected from a closer distance to the power plant. Storage costs of straw are higher due to the longer period of storage needed because of the limited harvesting period of straw. Pre-treatment costs for willow are much higher than for straw, due to the higher costs of chipping willow than straw, due to the need of using a more expensive type of chipper.

Table I: Comparing bioenergy chains

Feedstock to electricity	Straw	Willow
Transport costs (€)	29.700	45.600
Storage costs (€)	204.200	89.000
Pretreatment costs (€)	307.700	2.432.100

5 DISCUSSION

GIS-BIOLOCO can help stakeholders e.g. regional governmental bodies and companies, to design a first bioenergy chain on a specific location and assess what the spatial consequences and effects on environment, landscape and biodiversity of the implementing this chain would be. It will especially assist in comparing different chain options.

For this purpose, it is important that the future potential biomass maps are as realistic as possible. For the willow supply map of the presented case study, some crude assumptions were made. In the future, more sophisticated maps will become available for the tool for a variety of biomass feedstock (cropped and by- and waste products).

After the design of a biomass supply chain the environmental assessment can take place. Since the demand for bioenergy is mostly driven by the wish to reduce GHG emissions, and concerns have risen about the wider sustainability of these bioenergy chains, the integrated environmental assessment is a very important aspect of the tool. Currently specific indicators are being developed to quantify the impact of the chain in terms of GHG-emissions of the whole chain (including the cropping part) and effects on water quantity and quality, soil, landscape and biodiversity.

6 FURTHER RESEARCH

1. More realistic future biomass potential maps will be developed based on NPV values, commodity market developments and farmer decision behaviour.
2. Development of knowledge rules for predicting the spatial dispersion pattern of feedstock within different biomass delivery chains.
3. Further development and quantification of environmental indicators, e.g. GHG-balance, soil, water, landscape and biodiversity.
4. Adaptation of the GIS-BIOLOCO to a more generic environment to make the design and assessment of other types of bioenergy chains more efficient and easy,.

7 REFERENCES

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