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Attractive landscape and biofuel production – a possible combination?

Lovisa Blomqvist

Institutionen för bioenergi
Department of Bioenergy
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Abstract

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The aim of this study was to determine if it is possible to use abandoned farmland to produce biofuel and simultaneously promote an open landscape with possibilities of attractive views. Furthermore, the study aimed to present some landuse alternatives for fulfilling these desires. The study was performed on abandoned farmland of 100 ha close to Lake Siljan in Dalarna County, Sweden (Lat.60º51'N; Long.15º4'E; WGS84). View analyses were used and the costs and benefits for the implied actions were calculated. Management scenarios were developed to illustrate different options. Geographical Information System (GIS) was used to model the influence on the view. It was found that Lake Siljan would be more visible from the road/railroad if zones were opened up. The best view would be achieved if oat or other low landuses were used. A rotation system with broadleaves grown as short rotation coppice, would also improve the view compared to if nothing is done. The studied forested area of 100 ha held 9986 m^3 of stemwood, which corresponded to 5900 tonnes dry weight biomass in 2005. The present value of the timber, pulpwood and biofuel was calculated to 4.6 million SEK. The revenues would be 2.8 million SEK, if cut immediately (2005). The most profitable landuse alternatives were ley, fallow and broadleaves grown as short rotation coppice. The conclusion of the study is that it is possible to combine biofuel production and the creation of an open landscape along Lake Siljan. The management scenarios presented would allow scenic views at the same time as biofuel is produced on abandoned farmland. The profitability is more questionable and the dependence on subsidies is a vulnerable system involving a risk for changing conditions. However, if non-economic values such as culture, nature, rural development and tourism are considered, the proposed actions may be profitable. This study provides a basis for outlining guiding principles for extended biofuel production. Further work is necessary to fully cover all the aspects involved in biofuel production on abandoned farmland.

Keywords: biofuel, biomass, scenic views, landuse, GIS, scenarios, economy, abandoned farmland

Author's address: Lovisa Blomqvist, Department of Bioenergy, SLU, P.O. Box 7061, SE-750 07 UPPSALA, Sweden. E-mail: lovisa.blomqvist@bioenergi.slu.se

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Appendix

Papers I-II

This thesis is based on the following papers, which are referred to in the text by their corresponding Roman numerals.

I. Blomqvist, L., Berglund, U. & Hillring, B. Is it possible to attain scenic views while producing biofuels? *(Manuscript)*

II. Blomqvist, L. & Johansson, T. Biofuel production with scenic views – landuse alternatives and economy *(Manuscript)*

Note on the authorship of the papers

In Paper I, the aim and structure was set by Blomqvist, with comments by Berglund and Hillring. The data was collected, modelled, analysed and interpreted by Blomqvist. The discussion of the results was formulated by Blomqvist with comments by Berglund and Hillring.

In Paper II, the aim and structure was set by Blomqvist. Blomqvist and Johansson were responsible for the field data, the calculations and the analysis. Blomqvist was responsible for the discussion of the results.

Introduction

Alternative energy sources are gaining interest because of concern about the increasing green house effect together with rising oil prices. Biofuel is one alternative to fossil fuels, however it is land demanding. In some areas, this will lead to landuse conflicts, but in other areas there is a potential to combine other uses with biofuel production.

In Sweden, farms have closed and agricultural land has been abandoned. Left untended agricultural land becomes overgrown with raspberries and brushes and eventually becomes forest (Johansson, 1999a). Dalarna County, in the middle of Sweden, is famous for its old cultural landscape, especially the district of Siljan. It is a popular tourist attraction with its red-painted cottages and beautiful views of glittering water between forest-covered mountains. The cultural landscape of Dalarna holds values for agrarian history to an extent that is unique for the country (Dalarna County Board, 2003). Therefore, there is a desire to maintain the landscape and to keep the views of water.

The demand for biofuel and the urge for landscape management were the driving forces for this study. The main question at issue was whether it is possible to produce biofuel while maintaining views. An area south of Rättvik along Lake Siljan was chosen for the study. The work included measurement and calculation of what is presently growing on abandoned farmland. An attempt was made to calculate the actual cost of compensating the landowners for their forests and for restoring the land to farmland. The costs and benefits of future possible landuses were also calculated. Furthermore, the effect of the different landuses on the view from a scenic road was analyzed.

Biofuel – demand and supply

Bioenergy is energy derived from biofuels. Biofuels include all fuels produced directly or indirectly from biomass. This includes agrofuels, which embrace biofuels obtained as a product of energy crops and/or agricultural residues, and wood fuels, which include all types of biofuels originating directly or indirectly from woody biomass. Biomass is all material of biological origin, however, excluding material embedded in geological formations and transformed to fossil (European Committee for Standardization, 2003).

In 2005, the total energy supply in Sweden was 630 TWh, of which 112 TWh (18%) came from biofuels and peat (Swedish Energy Agency, 2006a). The use of biofuels in the Swedish energy system increased from 10% in the 1980s to 18% in 2005. The main part constitutes of domestically produced wood fuels (firewood, bark, chips, energy forest), byproducts from chemical pulpwood production, peat, waste (from industries, households etc.), and ethanol (in industry and as blended in gasoline 95 octane and main ingredient in vehicle fuels E85 and E92). The fuels are mainly used for heat production, but also for production of electricity.

As non-refined biofuels are voluminous, they are mainly used locally, although they can be refined to pellets, briquettes and powder to increase the energy density, facilitate handling and obtain better transport economy. In 2005, 1.5 million tonnes pellets (7.2 TWh) were used in Sweden. Moreover, biomass can be used to generate vehicle fuels, such as biogas, bioethanol and RME (rape methyl ester) (Swedish Energy Agency, 2006a). The use of gasoline, diesel oil, bunkers oil and aviation fuels in Sweden (including foreign shipping) has increased from 67 TWh in 1970 to 119 TWh in 2005 (Swedish Energy Agency, 2006b). However, as oil is becoming more expensive and the supply is not secure, alternatives are required. There are other possibilities for generating energy, including for example nuclear power which is disputed in Sweden; however, the challenge is to keep it both cheap and safe.

An extended use of renewable energy sources is supported by national (Swedish Environmental Protection Agency, 2005) and international objectives (European Commission, 2005). Many environmentalists consider truly renewable resources such as sun-, wind- and wave power together with biomass to be the only viable sources. The new solutions being developed are promising, but they often demand new distribution nets that are costly and time consuming to build.

Biofuel has one large advantage, as some fuels already have working production schemes and biotethanol for example can be used in existing distribution nets. It is possible to blend existing fossil fuels with biofuels to make them last longer, with almost no side effects. Some energy crop groups (oil and ethanol crops) have up-to-date technology at both the agricultural and transformation phases. Limitations to biofuel production are not technical but rather economic and logistical. The outputs are low in many areas, but there are wide margins for improvement, through rational techniques that keep inputs low (Venturi & Venturi, 2003). The production of upgraded biofuels in Sweden has been based on residues from the forest industry; however, it may be time to supplement this production with other sources which provide opportunities for the agriculture (Berlin, 2005), as well as developing handling and refinement systems for energy crops.

Only a few percent of Swedish farmland is used to grow energy crops. The largest fields of application are ethanol production, burning of straw, burning of oat, burning of *Salix* and RME production from rape (Johnsson, 2006). In Sweden, the reason for the small share of biofuels from agriculture is the well-developed forestry sector producing forestry leftovers such as sawdust, cutter shavings etc. Generally, energy crops provide the major potential for biofuel in Europe (Larsson *et al.*, 2006). The potential for energy crop production in Sweden has been estimated to 24-48 TWh long-term (Larsson, 2006), which corresponds to ca. 4-8% of the total energy supply in Sweden (Swedish Energy Agency, 2006a).

Although, Sweden may not be the most productive place to produce biofuel today, the growth patterns may change according to Tuck *et al.* (2006), who developed maps for the potential distribution of 26 potential energy crops in Europe according to suitable climatic conditions and elevation. Due to increasing temperatures, the potential distribution of temperate oilseed, cereals, starch crops and solid biofuels is predicted to increase in northern Europe by the 2080s and decrease in southern Europe (Spain, Portugal, southern France, Italy and Greece) due to drought. This means that the choice of energy crops in southern Europe may be severely reduced, as this area is particularly vulnerable to climatic change.

The interest in biofuel is increasing internationally. Within EU-25, 3.9% of the total energy consumption (70.5 EJ) was biomass in 2002 (Wright, 2006). The total biomass energy consumption in China, EU, Brazil, US, Canada and Australia was 17.1 EJ or 7.0% of the total energy consumption (245.0 EJ) in 2002 (Wright, 2006).

Biofuel - policy and regulation

Policy papers from the European Union (EU) state that the production of biomass for fuel should increase: in the White Paper of 1997 (European Commission, 1997), a goal was set for increasing the share of renewable energy in gross domestic energy consumption within the EU from 6% in 1997 to 12% in 2010. To achieve this, about 10 million ha agricultural land in Europe needs to be dedicated to the production of energy crops. In the Green Paper of 2006 (European Commission, 2006a), new proposals and alternatives are specified for the European energy politics. The dependence on imported oil should gradually be reduced by means of the biomass action plan (European Commission, 2005) and the strategy for biofuels (European Commission, 2006b).

Biofuel use is supported by Swedish national objectives (Swedish Environmental Protection Agency, 2005). Energy taxes are important for directing the energy consumption. Taxes on energy, carbon dioxide and sulfur motivate environmentally friendly alternatives such as biofuels, which are exempt from these taxes (Swedish National Tax Board, 2006). The combined taxes on oil, coal and other fossil fuels are often higher than the product price (Swedish Energy Agency, 2006a; Johnsson, 2006). Industries may choose to burn cereals, wood chips or wood pellets to obtain green certificates (LRF, 2005). Single house owners can apply for subsidies when converting from electricity or oil heating to heating with biofuels (Anon., 2005a, 2005b).

The political conditions for agriculture in Sweden changed with the entrance into the EU in 1995 (Naylor et al., 2005). The Common Agricultural Policy (CAP) aims to secure access to provisions, increase agricultural productivity and to provide farmers in the member nations a reasonable income. CAP offers different forms of supports for farmers. Since 1995, CAP has been reformed several times; most importantly the decoupling of the aid from production in 2005. Today, there are three different kinds of support for growing industry- and energy crops (Swedish Board of Agriculture, 2006a): single farm payments; specific support for energy crops; and national aid for establishing short rotation forest for energy use. In Dalarna for 2006, the single farm payments are 125.43 Euro ha^{-1} which corresponds to 1164 SEK ha^{-1} (1 Euro = 9.28 SEK, Swedish Kronor; Swedish Board of Agriculture, 2006b), the specific support for energy crops is 45 Euros ha^{-1} which corresponds to 418 SEK ha^{-1} and the national aid for establishing short rotation forest for energy use is 5000 SEK ha^{-1} (Swedish Board of Agriculture, 2006a).

Landuse

The large contribution of biofuel appointed by the policy objectives can only be obtained through the production and utilization of energy crops. There are two major difficulties to overcome in achieving this; scarcity of land and the relatively high costs of the bioenergy carriers produced. Scarcity of land is caused by competition between different landuses in available agricultural and forestry areas; urbanization, nature development and production of food, biomaterial and biofuel (Dornburg *et al.*, 2005).

There is a relation between land availability, material markets and biofuel supply (Dornburg *et al.*, 2005) and the application of biofuel may be limited by demand for land for other functions, this is especially obvious in densely populated countries. Within the EU, both energy-crop-based energy systems and extensification of agriculture receive policy support for environmental reasons (Broek *et al.*, 2001). However, both systems require more land than the conventional systems they replace, and as land is limited, a choice has to be made between the two. In the Netherlands, Broek *et al.* (2001) studied the use of energy crops by comparison with other landuses and revealed that it is better to dedicate more land to energy crops than to extensification of agriculture, provided that climate change, energy carrier depletion and acidification are the main drivers behind environmental policy. In the long-term, the development of systems based on energy crops can be expected to play an important role in reducing greenhouse gas emissions, energy carrier depletion and acidification. However, their widespread worldwide introduction and related landuse may limit organic agriculture and require additional measures in conventional agriculture for reducing the toxicity impact of pesticides (Broek*, et al.*, 2001).

In some areas, there is land availability, for example abandoned farmland. In Sweden, there has been a policy of decreasing agricultural production due to surplus cereals and competing difficulties with expensive production. This has resulted in abandoned farmland scattered all over the country. According to a study performed in Västerbotten County, in the north of Sweden, the density of available farmland is high in coastal areas, scattered in the inland parts and almost absent in the mountains (Larsson, 2006). Farmland abandonment usually occurs in marginal areas, where it has a negative influence on biodiversity and the landscape (MacDonald *et al.*, 2000). Environmental, structural, social and economical factors and policy reasons influence the abandonment of farmland.

The abandonment of farmland changes the structure of the landscapes in northern Scandinavia and in other areas with extensive forest cover relative to agricultural open land (Larsson & Nilsson, 2005). A mixture of forest and farmland is considered important to keep the scenic value of a landscape (Kumm, 1994; Tahvananinen *et al.*, 1996). Growing herbaceous energy crops could help to keep an open landscape and production of energy crops is an alternative to agriculture in areas threatened of abandonment (Larsson & Nilsson, 2005).

There is a trend towards intensive high-productive farming throughout Europe, resulting in abandonment of low-productive and small-scale agriculture (MacDonald *et al.*, 2000; Stoate *et al.*, 2001). In Eastern Europe and Russia, structural changes have led to abandonment of farmland (Peterson & Aunap, 1998; Feranec *et al.*, 2000). In Quebec, Canada, there is an abundance of marginal agricultural lands or abandoned farmlands that offer potential for growing *Salix* and poplar for energy production etc. (Labrecque & Teodorescu, 2003). Abandoned farmland is also frequent in eastern parts of the USA, as crops grow better and are easier to manage on the flat, fertile lands of the midwestern states (Bungay, 2004).

Rising agricultural productivity, changing economic policies supporting agriculture (CAP) and large farmland areas in the new member states imply that there will be more surplus cropland in Europe in the coming decades (Rounsevell *et al.*, 2005). This could leave more land available for energy crop production.

Landscape management

Swedish people show a preference for "the open landscape" (Saltzman, 2001). The reasons for this may be that it is a pleasant change to the great forests within the country, and that historically Sweden had more open cultivated land than today. In Sweden, uncultivated farmland is soon overgrown (Johansson, 1999a) and the shutting of farms leads to overgrowing of former open land. The coverage of trees and bushes was more extensive in 2001 than in 1996 (Naylor *et al.*, 2005). Open landscape is positive for tourism, but also residents are interested in the shape and beauty of the landscape. Landscape is more than "the view"; it is how we perceive the relationship between nature and culture in our surroundings (Landscape Character Network, 2006).

Both national objectives of Sweden (Swedish Environmental Protection Agency, 2005) and the EU (European Commission, 2003) advocate the importance of open landscape. Since the entrance into the EU in 1995, there has been environmental support for managing grasslands and landscape elements (Swedish Board of Agriculture, 2006c). In areas with environmental support, the changes are small, but in other areas, extensive overgrowing is in progress (Naylor *et al.*, 2005). Within Europe, the description, preservation and supervision of landscapes have become increasingly in focus (Naylor*, et al.*, 2005). The landscape concept has obtained more importance, for example with the European Landscape Convention, which Sweden signed in 2000 (European Landscape Convention, 2006).

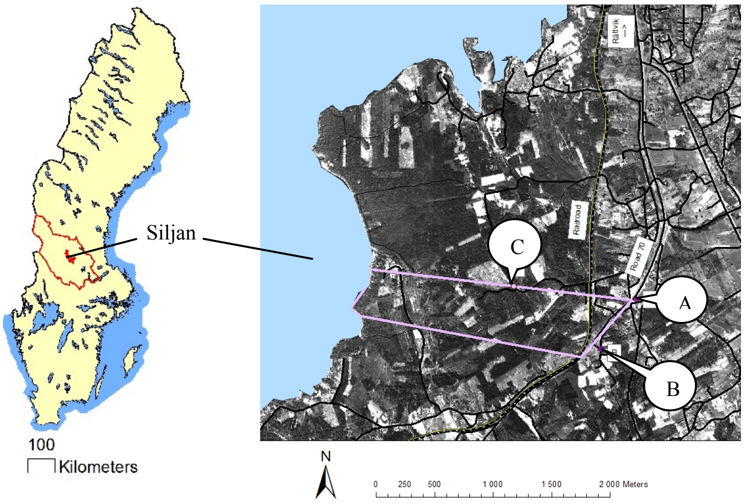

Figure 1. Left: map of Sweden with Dalarna County and within it Lake Siljan marked (©Lantmäteriet. 2004. Sverige1000plus). Right: Salunäset with viewpoints A, B and C marked and the white lines delineate the surveyed area (From map ©Lantmäteriet Gävle 2007. Permission I 2007/0071).

Dalarna

Dalarna County is located in the middle of Sweden (Figure 1) and mostly consists of sparsely populated countryside with many lakes surrounded by distant blue mountains covered with dense forests. Much of the land was cultivated in the beginning of the 20th century and the settlements by the beautiful lakes made Dalarna famous (Helmfrid, 1994).

There are several reasons for choosing Dalarna for this study: the landuse conflict and pronounced local goals for both biofuel production and open landscape (Dalarna County Board, 2003) make Dalarna a suitable area for this study. There is a conflict of interests concerning landuse in the area: hotel owners want to open up the landscape, but landowners may not find it economically practical or viable for other reasons to keep the area open. The conflict of interests concerning landuse is especially obvious around Siljan and other lakes, as this is where most tourists pass.

Living landscape and tourism

The traditional buildings in Dalarna are part of the Swedish cultural heritage and the special Dala settlements are unique in Europe (Helmfrid, 1994; Dalarna County Board, 2006a). These features make the Dalarna countryside an attractive place to visit and to settle in. Specialization, the shutting of farms and modern cultivation methods influence the nature- and cultural values of the landscape and the current biggest threat against the cultural landscape in Dalarna is the shutting farms and rural depopulation (Dalarna County Board, 2006a).

Income from tourism is very important for Dalarna and according to the environmental objectives of Dalarna (Dalarna County Board, 2003), it is important to have pleasant scenery in areas attractive to tourists and close to cities/villages. However, the abandoned farmland is growing over, the scenery disappearing and the landscape changing. Dalarna County actively works to meet the environmental objectives of Sweden. The environmental objectives of Dalarna, appointed in 2003 (Dalarna County Board, 2003), are regularly revised (Dalarna County Board, 2006b). Measurements for realizing the objectives have resulted in co-operations regarding energy, cultural landscape, forest etc. in Dalarna.

Biofuel production and use in Dalarna

In Dalarna, the total energy use was 17.3 TWh in 2004. Access to renewable energy is reasonable and the potential biofuel production in Dalarna has been estimated to 6 TWh year^{-1}. Current production and use of biofuel in Dalarna is about 3 TWh year^{-1} (Dalarna County Board, 2004). The interest in energy crops is increasing in Dalarna and the desire to keep the cultural landscape open raises motivation and possibilities (Dalarna County Board, 2006c), although there is a need for technical development. The Siljan region is working to develop new biofuel companies and in 2003, there was 317 ha energy forest in Dalarna County, which accounted for 0.3% of the arable land in Dalarna (Dalarna County Board, 2004). The district heating system of Rättvik municipality is mainly (98%) fuelled by biofuel (Sternberg, pers. comm., 2007). Rättvik municipality expresses an aim to develop the local biofuel market, describes measures to prevent the overgrowing of cultural landscapes and expresses that the biomass removed should be used for biofuel (Rättvik Municipality, 2000). There are also several other cities/villages burning wood fuels close to the area: Leksand, Siljansnäs, Säter, Mora, Falun, Hedemora etc.

Salunäset

The area around Lake Siljan may be the area in Dalarna most frequently visited by tourists. Celebrating midsummer in Rättvik is a popular activity often used in advertisements about Sweden. Tourists traveling toward Rättvik from the south will get the first view over Lake Siljan from Salunäset. Salunäset is a headland into Lake Siljan (Figure 1), and has a lot of former agricultural land according to old maps (Lantmäteriet, 1965). Salunäset was chosen as study area as it holds the qualities required: situated in a tourist passage, the appearance is economically as well as historically important, and Rättvik and other possible biofuel users are close.

Energy crops and other biofuel sources

Energy crops are woody or herbaceous crops specially cultivated to produce solid, liquid or gaseous forms of energy (European Committee for Standardization, 2003). Practically any plant could be used, although quick growth, high biomass yield and durability are desirable qualities. Four groups of energy crops can be distinguished: oilseed (oilseed rape, hemp etc.), starch crops (potatoes, sugar beet etc.), cereals (barley, wheat, oat, rye) and solid biofuel crops (reed canary grass, Miscanthus, short rotation coppice). There are also several ways to make use of the biomass. Biodiesel is based on oilseed crops and is derived through oil extraction and estrification. Ethanol can be derived through fermentation of crops rich in cellulose, sugar and starch. Biomass, in the strict sense of the word, can be obtained from species with high dry matter production treated with processes such as combustion, pyrolysis and gasification (Venturi & Venturi, 2003).

Multicrops and agroforestry

Dornburg *et al.*, (2005) studied the possibility of reducing the costs of biomass for energy and of minimizing GHG (greenhouse gas) emissions by using a crop partially for energy and partially for material purposes, the so-called multi-product crop. Material applications in this context were food, fodder, pulp and paper, construction material and chemicals. All agricultural and forest crops are suitable multi-product crops. The main component, the primary objective of production, is used for material production and the rest of the plant, the residue, can be used for energy purposes. Examples of the main component are seeds, lingo-cellulosic fibers, lumber, vegetable oils, starch and sugar. Examples of typical residues are bark, small twigs, plant stalk and leaves. Multi-product crop systems have the potential for improving the competitiveness of biofuel systems and for reducing GHG emissions (Dornburg *et al.*, 2005). Kuemmel *et al.*, (1998) examined a Combined Food and Energy (CFE) system in Denmark, and concluded that it is a profitable choice for farmers entering the heating market for smaller scale private customers, and smoothes the way for large-scale biofuel production.

Furthermore, agroforestry, when trees are integrated into agriculturally productive landscapes, is a possible way of producing biofuel. The trees can be used for many purposes: soil health, food security, shelter, medical trees, fruit trees for nutrition, fodder trees, timber and fuel wood trees, trees that produce gums, resins or latex products, and fertilizer trees for land regeneration (Graves *et al.*, 2006).

Byproducts

Firewood, chips and straw are fuels that can usually be produced at the farm or from forestry. These are competitive with heating oil. Pulpwood usually costs 120-150 SEK m^{-3}, which gives 100-120 SEK MWh^{-1}, chips cost 125-150 SEK MWh^{-1} and pressed straw costs 100-125 SEK MWh^{-1}, storage included (LRF, 2005).

Straw, as a byproduct of the cultivation of cereals, can be burned for energy and gives a positive energy balance (Nilsson, 1997) and does not require much extra input in terms of energy and work. However, straw is bulky and has a high ash content: this could be solved with short transportation distances and burners specially adapted to bulky fuels and high ash content.

The majority of wood fuel arises within forestry; branches and tops, other felling residues and firewood, as well as by byproducts from the timber-, pulp- and paper industries (Swedish Energy Agency, 2006a). Tops and branches could either be left in the forest or chipped and used as biofuel. At the sawmill, large amounts of sawdust and bark are produced. Logs that are damaged or of bad quality, for example affected by rot, and often also odd assortments such as grey alder, are not accepted for timber or pulpwood by the sawmills, but could be used as biofuel.

Stumps provide a significant volume of biofuel as a complement to tops, branches and other byproducts from forestry. Within this study, stumps were of interest, as they need to be removed for many of the suggested future landuses. If the stumps are sold as fuel, they could constitute an income rather than a cost. Removing stumps entails some advantages; site preparation needed before the next stand or crop is planted could be carried out in association with stump removal (Hakkila & Aarniala, 2004; Silvennoinen, 2006) and the risk for root rot (*Heterobasidion annosus* L.) decreases (Hakkila & Aarniala, 2004; Hildingsson, 2006). A consequence of stump harvesting is large broad-leaf growth (S:son Wigren, 2005) which could be good for some of the proposed landuses in this study. Stumps are mainly extracted from fertile areas dominated by Norway spruce (*Picea abies* (L.) Karst.) (Hildingsson, 2006). In Sweden, the interest in stump clearing has increased recently in areas suffering the consequences of the storm “Gudrun” in January 2005 (Hildingsson, 2006). The total potential of stump energy in Sweden has been estimated to 7-14 TWh (Swedish Environmental Protection Agency, 2006).

The main problem with the use of stumps for energy is that it is contamination from rock and soil. However, if large-scale heavy fixed crushers are used, small impurities do not prevent the material from being burned in fluidized-bed furnaces at large power plants (Hakkila & Aarniala, 2004). Another problem with stump extraction is the effect on the flora and fauna, and according to Swedish Society for Nature Conservation (SSNC), it causes drastic effects on the forest ecosystem. However, efforts are made to protect environmental values: most of the roots are left in the ground, and the largest stumps, > 50 cm in diameter, are left as they have a high biological value (S:son Wigren, 2006).

Cereals

Surplus cereals and rising energy prices have increased interest in the burning of cereals (Svensson, 2005), especially as there are now special burners and boilers for burning cereals. Oat (*Avena sativa* L.) appears the cereal best suited for burning (LRF, 2005): the soft grain renders it relatively inflammable, the melting temperature of the ash is relatively high and is fully liquid at 1550ºC; and sintering problems are uncommon (LRF, 2004). Oat also has the highest energy content due to the high fat content and is a good crop in the crop rotation (Blomgren, 2004). Oat is a competitive fuel for residence heating, especially for the farmer (LRF, 2004), and it can be grown far north (Shenet, 2006).

Reed canary grass

Reed canary grass (*Phalaris arundinacea* L.) apperas to be the highest yielding graminaceous plant grown as energy- and fiber crop in Sweden (Pahkala *et al.*, 2003). Reed canary grass (RCG) yields are equally high or higher in northern Sweden than in the rest of the country, where most of the farming occurs. RCG could produce a good harvest for at least 10-12 years, if it is harvested in the spring as last year's grass (Pahkala *et al.*, 2003). According to Landstrom *et al.* (1996), the average yield of RCG is 8.5 tonnes d.w. (dry weight) ha^{-1} $year^{-1}$ in Sweden. If harvested in the spring, it has better combustion qualities. RCG is usually mixed with peat, chips or a mixture of bark and wood shavings to obtain a fuel with good burning qualities (Pahkala *et al.*, 2003). RCG can also be refined to pellets, briquettes and powder. The high ash content can be a problem; however, RCG pellets and briquettes combust well, if the boilers are adapted to ash rich fuels (Larsson *et al.*, 2006). Due to its bulky nature, transportation and handling of RCG should be minimized and for profitable harvest of RCG, transportation should not be more than 10-15 km (Larsson, 2006).

Hemp

Hemp (*Cannabis sativa* L.) is an annual herbaceous plant with qualities that make it suitable as an energy crop as it needs little or no biocide, restrains weeds efficiently and has limited demands on fertilizer and crop rotation (Van der Werf, 1994). Hemp yields up to 10-15 tonnes d.w. ha^{-1} $year^{-1}$ and can be cultivated far north (Struik *et al.*, 2000; Sundberg & Westlin, 2005; Forlin, 2006). In Sweden the use of hemp as energy crop has been prohibited due to the presence of the phytochemical drug component δ-9-tetrahydrocannabinol (THC). However, in recent years industrial hemp with low THC content has become wide spread and from 2007 hemp is approved as an energy crop, making it possible to apply for single farm payments and specific support for energy crops for hemp cultivation (Swedish Board of Agriculture, 2006d).

Wood fuel from pioneer tree species

One interesting concept for producing biomass is to grow trees under a short-rotation, intensive-culture system. These systems rely on fast-growing hardwood tree species, close planting densities, short-rotation harvests, improved genetic stock, fertile sites and coppice regrowth (Geyer, 2006). Regeneration through sprouts and suckers with small additional cost is a useful possibility. Fast growing tree species with a rotation period of 20 years or less could be entitled to specific energy crop support (Anon., 2004), although alder and birch have not been included so far (Hansson, pers. comm., 2006).

Tree species grown for energy production should have a short rotation period and species that rapidly increase their leaf area and prioritize aboveground growth are desirable (Telenius, 1999). Pioneer species usually fulfill these criteria. *Salix* species are commonly used as short rotation coppice (SRC) and the production is highest on damp soils with good access to nutrients. The existing *Salix* cultivations yield ca. 4-5 tonnes d.w. ha^{-1} $year^{-1}$, but new ones with improved sort material give ca. 7-11 tonnes d.w. ha^{-1} $year^{-1}$ (Johnsson, 2006). Frost hardy *Salix* varieties suitable for the Siljan area are Doris (*Salix dasyclados*), Karin (((*Salix schwerinii* x *S.viminalis*) x *S.vim.*) x *S.burjatica*)) and Gudrun (*Salix dasyclados*) (Larsson, pers. comm., 2006).

Even though *Salix* is the most common species used in Swedish coppice systems, other species also have potential. The most abundant broadleaved pioneer species in Sweden are birch spp., European aspen (*Populus tremula* L.) and alder spp. (Swedish Forest Agency, 2004). Studies by Johansson (1999b, 2000) showed that grey alder (*Alnus incana* (L.) Moench), common alder (*Alnus glutinosa* (L.) Gaertn.), silver birch (*Betula pendula*) and downy birch (*Betula pubescens*) possess qualities that make them possible to grow as SRC. Alder is undoubtedly an interesting crop due to its symbiosis with the actinomycete *Frankia* which has the ability to fix nitrogen (N_2) from the air (Johansson, 2000; Jorgensen *et al.*, 2005). A mean annual increment of 4.38 tonnes d.w. ha^{-1} $year^{-1}$ for grey alder (*Alnus incana*) and 3.11 tonnes d.w. ha^{-1} $year^{-1}$ for common alder (*Alnus glutinosa*) on agricultural land was reported by Johansson (2000). In dense plantations on agricultural land, grey alder have been reported to yield up to ca. 8 tonnes d.w. ha^{-1} $year^{-1}$ (Telenius, 1999). The mean annual increment was reported as 4.48 tonnes d.w. ha^{-1} $year^{-1}$ for silver birch stands growing on abandoned farmland and 2.70 tonnes d.w. ha^{-1} $year^{-1}$ for downy birch (Johansson, 1999b).

Studies by Johansson (1999c), Telenius (1999), Labrecque & Teodorescu (2005) show that *Populus* spp. are also suitable for SRC systems. Hybrid aspen (*Populus tremula* L. *x P.tremuloides* Michx.) yields up to ca. 9 tonnes d.w. ha^{-1} $year^{-1}$ (Telenius, 1999).

In order to secure a reliable biomass supply, it is important to identify new varieties well adapted to northern climatic conditions for increasing the numbers of taxa that could be used by farmers and landowners for biomass production. Large monocultures should be avoided as they are vulnerable to insect and disease attacks. Energy forests have been established and many studies about biomass production with broadleaves have been performed (Johansson, 1999b, 1999c, 2000; Telenius, 1999; Uri *et al.*, 2002; Labrecque & Teodorescu, 2003, 2005; Jorgensen *et al.*, 2005).

Aim

The aim of this study was to determine whether it is possible to use abandoned farmland to produce biofuel and simultaneously promote an open, living landscape with maintained views. Further, the study aimed to present some landuse alternatives fulfilling these desires. In order to determine whether it is possible or not, view analyses and calculation of the costs and benefits for the implied actions were made.

This study principally dealt with Swedish conditions, and crops suitable for the climate in Dalarna were chosen: oat, reed canary grass, hemp, *Salix*, hybrid aspen, alder and birch. Leys and fallow were also considered as landuse alternatives, however not producing any biofuel. Multicrops and agroforestry were mentioned but not used in the calculations. An attempt was made to find a system of landuse that satisfied both landowners and tourists/hotel owners. This was by no means an exhaustive analysis, there are still more aspects to consider.

The questions at issue were:
Is it possible to produce biofuel with maintained views?
How is it possible to produce biofuel with maintained views?
Is it economically viable to produce biofuel with maintained views?
Is it viable if all aspects are considered?

Material and methods

A system approach was used to describe, analyze and plan the complex system: economy – energy supply – environment – culture – tourism – landscape. The requirements and consequences of each of these aspects were identified and considered. Tourism was identified as the main driving force for endurance of the cultural landscape in Dalarna, however, the inhabitants' wishes for a pleasant environment were equally important. Production of biofuel was considered to be another way to contribute to the economy of these regions.

The area studied was an area of 100 ha at Salunäset south of Rättvik in Dalarna County in the middle of Sweden (Figure 1). In the survey study, GPS and Geographical Information Systems (GIS) were used for mapping the area. The data collected in the field with GPS (Magellan Meridian Color) was transformed to the GIS (ESRI, 2004) with MapSend (Thales Navigation, 2002).

Scenarios were used to study different aspects of possible future landuse alternatives in the area of 100 ha (Figure 1). Three management scenarios were used in both papers:

Scenario 1: All stands were cut and replaced by low crops i.e. oat, reed canary grass, hemp, ley or fallow.

Scenario 2: The second scenario implied that half the area would be used for low crops and the other half would be alder/birch SRC. Low growing crops were most desired close to the road, and alder and birch grown as SRC could be used in the rest of the area.

Scenario 3: A rotation system preferably with alder/birch grown as SRC. The rotation system could e.g. include five zones of alder/birch, where one zone was cut every three years. Consequently, there would always be a zone of maximum three-year-old coppice with a height of about 2m. Each zone would then be cut every 15 years at a height of about 10m.

Paper I

The first study was made mostly by means of GIS analyses but field experience was helpful to fully understand the present situation at Salunäset. The landscape analysis was restricted to the impact on the view. Scenarios were used to try to compare how different landuses would influence the landscape and the possibilities of beautiful views. With a GIS-model, the view of Lake Siljan was visualized with different landuses. View analyses were performed through viewsheds from a specific viewpoint (A). The software used was ESRI ArcGIS 9.0; ArcMap and ArcScene extensions (ESRI, 2004). For the view analyses, elevation data (Lantmäteriet, 2001) and kNN (k Nearest Neighbor) data were used (Reese *et al.*, 2003; Granqvist Pahlén *et al.*, 2004).

Paper II

The second study was conducted through a survey study of forest stands, calculation of the standing volume and biomass, as well as the economic value of the forest stands, and finally cost and benefit calculations for future landuse alternatives. The survey study was conducted in an area of 100 ha on Salunäset south of Rättvik in Dalarna County in the middle of Sweden (Figure 1). Within the chosen area, all stands were identified and measured. In each stand, the mix of tree species was determined, as was the diameter at breast height (mm), height (m), basal area (m^2 ha^{-1}), number of stems ha^{-1} and age (years) of each species. The forest variables were used to calculate the volume, biomass and the value of timber, pulpwood and biofuel for the measured area of 100 ha.

The economic analysis included two ways of determining the value of the forest at the 100 ha measured area at Salunäset. The economic value obtained if the 100 stands were cut immediately (2005) was determined for each stand and then totaled. However, the actual value for the landowners was better described by a present value calculation. The net present value at the year of germination, if managed until clear-cut, was calculated for each stand individually and then extended to 2005. Then, the values for 2005 were summed. The net present value, considering timber, pulpwood and biofuel, was calculated according to the formula (Faustmann, 1995, 1849):

$$P = (w*(1+r)^{-a} - c*(1+r)^{-a}) \qquad (1)$$

Where:
P = present value
r = rate (3%)
a = age of the stand at management
c = costs (cleaning and thinning)
w = benefits (thinning and clear cutting)

The income from stump biofuel was assumed to cover the costs of stump extraction and site preparation. The costs and benefits of the selected landuse alternatives were calculated according to a method developed by Rosenqvist (1997). To simplify the calculations, only one crop was considered at the time and, therefore, multicrops and agroforestry were not considered. Updated versions of calculi by Rosenqvist (pers. comm., 2006) were used and adapted to fit the present study. Alder and birch already present at the site were assumed as a base for a future rotation system; thus, the establishment cost of alder and birch was set to zero.

Results

Paper I

The analysis in Paper 1 confirmed that a zone cleared of trees would make it easier to see Lake Siljan from viewpoint A at national road 70. To work with zones was determined to be efficient, when scenic views were to be achieved with as little impact on the current landuse as possible. Management scenario 1 gave the best view and the largest impact. To distinguish between the other two management scenarios was more difficult, although Management scenario 2 gave broader view possibilities by national road 70. All three management scenarios clearly improved the views than if nothing was done.

Paper II

The measured area of 100 ha was calculated to hold 9986 m^3 or a biomass of 5900 tonnes. The present value of the timber and pulpwood in the measured area of 100 ha was 4,626,000 SEK in 2005. However, the actual value, if cut immediately in 2005, was calculated to 2,816,000 SEK. As the measured area corresponded to the surroundings, it was conceivable to multiply the values to match a desired area. For the 760 ha of Salunäset, it would be 43,660 tonnes or 73,900 m^3 at a present value of about 35 million SEK, and if cut today it would be worth about 21 million SEK. Future possible landuses were also analyzed. The profit of each crop is summarized in Table 1. For details, see results presented in Paper II.

Table 1. Results and support for the landuses chosen, SEK ha^{-1} $year^{-1}$.

Crop	Result of calculi	Compen-satory allowance	Single farm payments	Specific energy crop support	Total
Oat	-2971	1000	1164	418	-389
Straw	0	-	-	-	0
Ley	-1543	1960	1164	-	1581
Fallow	-700	-	1164	-	464
RCG	-1582	-	1164	418	0
Energy hemp	-4942	-	1164	418	-3360
Salix	-720	-	1164	418	862
Hybrid aspen	-1087	-	1164	418	495
Birch	0	-	-	-	0
Alder	0	-	-	-	0

Either the area could be used for one particular crop or several landuses could share the area, and there are many possible combinations of landuse. In the calculations, each crop/landuse was considered singly and possible incomes were calculated per hectare (Table 1). Then, potential combinations were reviewed according to the management scenarios presented.

The scenarios were developed to image what different choices could mean in reality. The cost for compensating the farmers for the 100 ha measured would be about 4.6 million SEK and the benefit from the forest if cut today would be about 2.8 million SEK, leaving a cost of 1.8 million SEK for changing landuse. The first scenario would give maximum of 158,100 SEK (ley) and cost up to 336,000 SEK year^{-1} (hemp) for 100 ha (Table 1). With ley in this scenario, the cost for changing landuse would be repaid in 11 years. The second scenario, half the area would be low crops and half the area would be alder/birch SRC, would give 79,050 SEK (ley) at the most and cost up to 168,000 SEK year^{-1} (hemp). The cost for changing landuse would be repaid in 23 years. The third scenario, suggesting a rotation system with alder and birch on all of the 100 ha, would give biofuel for the local market but no income according to the calculus used in this study; with *Salix* the cost for changing landuse would be repaid in 21 years.

Discussion

Is it possible?

In order to answer the question whether it is possible to achieve an open cultural landscape and at the same time produce biofuel, many aspects need to be considered: landscape preferences, nature and culture values, the point from which the view is requested, gradient, economic profitability, what kind of subsidies that are available, landuse conflicts etc. Although there are management scenarios that would allow scenic views along side biofuel production in the area, the profitability is more questionable. The dependence on subsidies results in a vulnerable system and involves a risk of changing conditions. Even though there is already a local market with development possibilities for different kinds of biofuels in the area, competition over prices and the cost of removing the forest could present problems. Further work is necessary to fully cover all the aspects involved in biofuel production on abandoned farmland and other aspects may become visible once a management scenario is implemented.

Biofuel in Dalarna

In order to compare the outcomes for different landuse options, several crops were included in the study. The best economic option for producing biofuel in the study area would be to use tree species; that require minimum management, provide a solution to earning some money on poor land and are flexible in harvest time so it is possible to harvest at the most profitable moment. As alder and birch are abundant in the study area and they quickly make use of available land through sprouts and suckers (only grey alder), they provide a good basis for SRC. Although the establishment and management costs would be almost negligible, the low yields would give lower economic returns than if hybrid aspen or *Salix* were grown. However, low-intensity alder and birch SRCs are better suited for the inaccessible Siljan area, which is situated at quite high latitudes, than intensive *Salix* and hybrid aspen plantations. Alternatively, energy crops such as reed canary grass and other grasses could be used. RCG and hemp can be grown at high latitudes and should be suitable in Dalarna. Although hemp has good potential, its development as an energy crop has been restricted by regulations. Traditional agricultural crops have also proven be viable as biofuels and present an important advantage as the farmers' agricultural equipment can be used. Oats can thrive at high latitude and have better combustion qualities than other cereals. However, there are ethical concerns over the use of cereals as biofuels. Accordingly, the main biofuel alternatives in the study area were birch/alder SRC, RCG or oats.

Views of Lake Siljan are possible to obtain with both the use of cereals/RCG/hemp/ley/fallow and with a rotation system of alder/birch/*Salix*/hybrid aspen grown as SRC (Paper I). SRC comprise good economical conditions but it introduces new landscape characters and can be regarded as controversial. If the old cultural landscape of Dalarna is to be preserved, sprout forest may not be considered convenient. However, SRC could actually be good for the perception of landscapes; Skärbäck & Becht (2005) noted that the introduction of new color into the arable landscape and the spatial variation from year to year could be advantageous. To maintain Dalarna as an attractive place to live and visit it is important that its values are preserved simultaneously with development and changes. At the same time as the landscape needs to be managed new activities and employment are needed in rural areas. Biofuel production could be a solution in some areas, the landscape character would change slightly, but the values would be preserved more than if the landscape was left unattended.

Projects and local solutions

There are already many ongoing projects set to attain an open cultural landscape around Lake Siljan (Dalarna County Board. 2006d; Wennberg Öhrnell, 2006). Grazing associations, where a number of farmers cooperate to look after some grazing animals on common or private land, is one kind of project (Sörbygge, 2006), and may be a good forum for further cooperation. Biofuel production is more profitable if the products are sold locally and if activities are co-operative: this could include buying a common cutter and/or chipper and to co-operate on biofuel transports to Rättvik or other local boilers. In the village of Utby at Salunäset, there are plans for building a wood chips fired boiler (Sternberg, pers. comm., 2007). If this was realized, it would provide an ideal user for wood chips from alder, birch or *Salix* produced in the area. If cereals or reed canary grass are considered as the best crops in the area, investment in a burner adapted for burning these bulky and ash rich crops could be profitable.

Agriculture is a large user of energy. Most farmers are dependent on big suppliers and companies. Local solutions with for example energy production at the farm diminish farmers' vulnerability (Blomgren, 2005; Berlin, 2006). With more energy production within agriculture the exploitation of risk decreases. Higher energy prices result in higher expenses, but also higher income. A farmer could be primary product supplier for a big plant producing ethanol or RME or he/she could produce energy crops for chips in a district heating plant. Maximum profit is achieved if the farmer is part of the whole chain; producing the crop and being a partner in the district heating plant (Berlin, 2006). One way of spreading the risks is to grow many species and invest in many projects at once.

Profitability

Before introducing new landuses into the area, the forest needs to be removed and according to the calculations within this study, the difference between the income if the forest was cut immediately (2.8 million SEK) and the cost for compensating the landowners (4.6 million SEK) would be 1.8 million SEK for the 100 ha studied. After a landuse change, it would take at least 11 to 23 years to recover the costs of compensating the landowners for their forest, according to the presented management scenarios.

SRC systems (*Salix*, hybrid aspen, birch, alder) appear the most profitable options for producing biofuel. This is in accordance with Johnsson (2006), implying that the most profitable ways of producing biofuel are to cultivate *Salix* for burning or rape for RME-production. In areas with lower yields, the most profitable alternative may be to keep the land open with single farm payments without using the crop, according to Johnsson (2006), which also corresponds to the findings of this study; ley and fallow are as profitable or better than SRC systems. The most profitable landuse option studied was to use the land for ley, however this would not produce any biofuel.

Production of energy crops on abandoned farmland could be more profitable if it was fertilized with sludge. Since 2005, deposition of organic wastes, such as sludge, has been prohibited in Sweden (Anon., 2001). Sludge as energy crop fertilization helps address the increasing sludge handling problem and reduces the need for commercial fertilizers. The farmer could decrease the cost of fertilization by 30 SEK MWh^{-1} and in addition receive payment for accepting the sludge (Larsson, 2006).

One inevitable problem with biofuel is that it is bulky in proportion to its energy content. To make biofuel production profitable, transport should be as little and short as possible. According to a study by Larsson (2006), the distance to the farm should be no more than 10-15 km for a profitable harvest of reed canary grass. An American source recommends avoiding transporting biomass from sites more than 100-200 km from the factory (Bungay, 2004).

One criticism of biofuel is that it uses a lot of energy in the production and it is true that current systems for energy crop production use fossil fuels. However, the energy harvest has been calculated to almost six times greater than the invested energy for oat grown as energy crop, and there is a possibility to double the energy produced if straw is utilize as fuel as well (LRF, 2004). Ethanol and RME provide one and a half times more energy than they take to produce (Berlin, 2006). This energy surplus may improve with further research and development. Overall net production of energy, economic efficiency and reduction of greenhouse gases tend to increase with higher crop yields, however, other ecological criteria are negatively affected (Hanegraaf *et al.*, 1998).

Economy is usually the factor deciding landuse. However, new possibilities are presented as the single farm payment scheme implies that the support is decoupled from production. In addition, the specific support for energy crops introduced in 2004 stimulates the production of energy crops. The possibility to transmit payment entitlements through trade or rent and the national reserve of payment entitlements provide opportunity for restoring pasture, hayfields etc. The single farm payments are, in a way, society's price on open landscape.

Profitability usually only considers financial results, however there are other important aspects that are difficult to assign a monetary value. If aspects such as landscape view, rural development, biodiversity and culture are considered, the landuse alternatives proposed in this study could be regarded as profitable. In the future, tourists may need to pay a fee to be able to experience the cultural landscape of Dalarna, as well as untouched nature or other desirable features in other places.

Environmental effects

This study was limited to view and economic analyses, but other important aspects cannot be neglected. A change in landuse from forest to agricultural crops would greatly impact the ecosystem in the area. Whether there are endemic species in the area, and how they would be affected by the proposed landuses needs to be investigated; the nature values should be evaluated and considered.

The environment is of course affected when landuse is changed from agriculture to energy crops, forest to agriculture, not managed to perennial crops etc. Perennial crops are generally better for the environment than annual crops as the plant nutrient leakage and the use of biocides and pesticides is smaller for perennial crops. The disturbance at the production site is also smaller with perennial crops (Johnsson, 2006). When changing from agriculture to cultivation of energy crops, emission of green house gases, nutrient leaching and erosion may be reduced (Börjesson, 1997). Energy crops, especially perennial grasses, are considered to improve soil water and nutrient-holding capacity, soil organic matter and soil structure (Kort *et al.*, 1998). Therefore, they are useful on easily eroded soils and soils depleted of nutrients and organic matter through intensive cropping. Energy crops are generally more tolerant to extremes in fertility and moisture content of the soil than agricultural crops (Paine *et al.*, 1996). In addition, energy crops such as *Salix* and reed canary grass can be used to purify municipal wastewater and sludge. *Salix* cultivation could also be used to reduce the content of heavy metals in the soil. These environmental effects should be considered, as they potentially increase the value of energy crops. Governmental measures to achieve economic incitements for farmers should reflect the national interest of these positive environmental effects. Börjesson (1997) estimated the total economic value of the positive environmental effects of replacing annual food crops with perennial energy crops to 1-130 SEK MWh^{-1} biomass.

One drawback with annual and short-life crops is that they naturally contain large amounts of alkali which may cause problems during combustion with depositions, high temperature corrosion, agglomeration and sintering which reduce capacity, efficiency and availability of thermal conversion plants using biomass (Baxter *et al.*, 1998). There are however advantages when using agricultural crops for energy production; the farmers can use their agricultural equipment and switch to energy crops without large investments. The short rotation period offers quick cash and provides flexibility as the farmer is only tied to the chosen landuse for a year at the time. Another important aspect is that cereals and other annual crops only reach 1m in height and there is no risk of blocking desirable views. Annual crops make a quicker use of the available land than perennials and usually have higher yields. The use of traditional agricultural crops for energy production on farmland is preferred when aspects such as landscape view, biodiversity, and flexible landuse are taken into account according to Johnsson (2006).

In northern regions annual crops show better yields but in southern regions perennial crops tend to produce higher yields (Hanegraaf *et al.*, 1998). Energy balance calculations, the harvested energy in relation to the invested energy, give the best result for energy forests whereas cereals give poorer exchange. For efficiency, it is appropriate to use the biofuels for heat and power production and secondarily for production of liquid fuels. The transportation loss is smaller for biofuel than for fossil fuels as the biomass is usually grown close to where it is used (Johnsson, 2006).

If the environmental aspects are giving high priority leys and fallows present good alternatives to the biofuel crops as they could imply fewer disturbances of the land and better conditions for maintenance of biodiversity.

In a larger perspective

The results of this study could be applied to other areas. Although many details in the study are site specific, the idea is that it should be comparable with other regions with similar prerequisites: energy shortage, unattended land and a desire for an open landscape. Landuse conflicts are common in densely populated countries and areas where abandoned farmland is overgrowing are to be found in many countries: Eastern Europe, Russia, Canada etc. Due to the current agricultural policies, agriculture will decrease further in many regions and which landuses will replace agriculture remains to be seen; energy crops, grazing with horses, buildings, industries etc.

The worldwide energy system faces a complex challenge as the available fossil fuels are becoming limited or at least very expensive. The high consumption of energy in western countries is difficult to restrain and alternative energy sources receive more attention, with biomass as an important option. The many ways of producing, refining and using biomass need to be carefully studied and evaluated and it is important to find solutions where several interests can share an area, especially in densely populated regions and close to big cities. In this study, one case of interest conflict was studied, but there are others.

The qualities of each site need to be considered, as different landuses may be suitable in different areas. Cultivation of annual energy crops demand some use of fossil fuels and disturbs the area more than if the land is left untilled. Cultivation of perennial energy crops creates less environmental impact, but growing energy forests affects the landscape more than commercial agricultural crops. All effects need to be considered before deciding the best way to produce biofuel in each area. The results of this study could be applied in other areas, however the following objectives should be considered when deciding the most suitable crop:

- How important is the view in the specific area?
- How important is the income in the specific area (i.e. are there other ways to support the activities)?
- What are the conditions in the specific area: tourism, economy, ownership, growing conditions, nature values etc.?
- What are the prerequisites of the farmer, in terms of equipment, desires etc.?

If biofuel production is not an aim in itself, but rather the landscape and scenic views is the main goal; ley, fallow, pasture or traditional agriculture are just as good choices as low-growing energy crops. Conversely, if the view is not important, traditional forestry may be considered for producing timber as well as considerable amounts of felling residues that can be used for biofuel production.

Development possibilities

The model used to study how different landuse would influence the landscape and the possibility to views could be further developed. Only height was analyzed but other aspects could be included; color, degree of variation etc. The method could also be adapted for use in more urban areas, for example to illustrate what crops are suitable in the near surroundings of big cities.

The calculations of future landuses provides an idea of what the different choices would imply economically, and may reveal differences in the results, if the inputs are altered to better fit particular cases. The profitability of the energy crops discussed in this study is highly dependent on regional conditions: climate, storage facilities, transportation efficiency etc. Therefore, the conditions in each area where energy crops are established should be investigated. To simplify the calculations, only one crop was considered at the time and thus multicrops and agroforestry were not considered in this study, although they may involve profitable possibilities that could be investigated.

Development of boilers that can handle fuel with high ash contents is a requirement if pellets from energy grass, cereals and ash rich forest products are to be used in single houses or smaller boiler rooms (Larsson *et al.*, 2006). The combination of stump extraction and site preparation, the effects of stump removal on seedlings growth and survival, and the effects on regeneration costs, including clearing costs should be further examined (Saarinen, 2006).

Conclusion

The conclusion of this work is that there are management scenarios that would allow scenic views simultaneously with biofuel production in the area. Biofuel production on abandoned farmland in Dalarna provides opportunity for continued activity in the countryside and a well-managed landscape improves the conditions for tourism. Profitability is more questionable, but if aspects such as landscape view, rural development, nature and culture values etc. are considered, the proposed landuse alternatives could be regarded profitable. The conditions at a specific site and the main purpose should be carefully considered when choosing the most suitable crop. Low energy crops are the best suited to areas where there are important tourist passages and where visual impression is vital. However, SRC presents better economic results, and could be managed according to a rotation system where views are always possible in some direction. If biofuel is not essential, ley and fallow could be considered, as they provided the best economic results in this study. This study provides a basis for outlining guiding principles for extended biofuel production. The results of the study could be applied to other areas with similar conditions, although further work is necessary to fully cover all the aspects involved in biofuel production on abandoned farmland.

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