Alternative forest management facilitates the harvest of bio-fuel in young stands

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Abstract:
The extraction of bio-fuel in young stands is steadily increasing in Swedish forestry management. The task of developing and adjusting techniques and methods is improving which results in increased efficiency and cost effectiveness. Although there is still much to develop before the harvest of bio-fuel in young stands becomes an overall accepted and profitable method.

The majority of bio fuel harvests in young stands is still conducted with traditional methods, i.e. with strip roads, between which the trees are thinned selectively. The method is slow and expensive. In addition the stands are commonly cleaned at least once before the harvest of bio-fuel. The density of the stand is seldom higher than approximately 2500-3000 stems per hectare and the average stem diameter is small. A removal of approximately 30-40% implies a relatively small harvested volume per hectare and high costs per m^3 *extracted. To increase productivity new management strategies must be tested and evaluated. One possible way is to increase the density in young stands with the aim of increasing the harvested biofuel volume in young stands. Another way is to adjust the forestry from pulp and saw timber production towards intensive management of biofuel.*

The increased need of renewable energy, of which biomass from forestry is an important source, thus leaves us with some important questions:
- *How to increase machine-efficiency and productivity?*
- *What effect will an increased harvested volume of bio-fuels have on the future access of pulpwood and timber?*
- *What effect will an increased harvested volume of bio-fuels have on the economy?*
- *What effect will it cause to the environment*

Keywords: Silviculture, bio-fuel, energy wood

1 Introduction

The global use of coal and oil-products has to decrease to reduce impact of the environment and emissions of CO_2 to the atmosphere. In Sweden official reports have resulted in a proposal of possible ways to become independent of fossil fuels (Oljekommissionen 2006). Until 2020 the goal in Sweden is to reduce the use of fossil fuels with 40-50 % in transports, 100% in heating of buildings and 20-40% in the industry (Oljekommissionen 2006). The key to success is a decrease in the energy use together with an increase in the use of renewable energy sources of which biofuels from agriculture and forestry are important contributions.

The use of trees from young stands and thinnings as an energy source is steadily increasing in Swedish forestry management (Richardsson et al, 2002). Partly the volume of energy-wood from young stands comes from a shift from pulpwood to energy wood but also volumes from trees that previous were left in the forest increases (Björheden et al. 2010). This increases the need of developing and adjusting methods as well as techniques in treatment of young stands (Nordfjell et al, 2008). The demand from the timber-, pulpwood- and energy-industries has to be secured and there is still much to do concerning the efficiency and cost effectiveness before the harvest of bio-fuel in young stands becomes an overall accepted and profitable method (Kärhä et al, 2005). In addition there are questions to answer concerning environmental consequences of different strategies (Röser et al, 2008).

Productivity and efficiency in harvest of young stands can increase trough geometrical treatments. This allows cutting of more than one stem at a time and thereby decrease the time consumption per stem. Trials and studies of geometrical thinnings (for example thinning in corridors) have been made at SLU and Skogforsk (Bergström 2010 and Fogdestam 2010). In addition there have been analyses of the possibilities to plant, self generate or sow more stems per hectare and allow denser stands until the harvest of energy wood (Ulvcrona 2011) The results are very promising and there are also possibilities to use fertilizers to increase the production capacity of the ground.

The increased need of renewable energy, of which biomass from forestry is an important source, thus leaves us with some important questions:

- How to increase machine-efficiency and productivity?
- What effect will an increased harvested volume of bio-fuels have on the future access of pulpwood and timber?
- What effect will an increased harvested volume of bio-fuels have on the economy?
- What effect will it cause to the environment?

In this paper three different strategies will be compared and discussed concerning productivity, cost efficiency and environmental consequences:

- Traditional management where volumes from young stands will supply the pulp- and paper industry with pulpwood (reference)
- Increased harvest of bio-fuel and energy wood from young stands with planting and harvest in rectangular patterns. A more intense forestry with denser young stands together with an increased use of fertilizers is necessary to avoid a decrease of supply to the pulp- and paper industry.
- 100% of the volume from Swedish forestry supplies exclusively the energy industry. This includes intensive management with short rotation periods, dense young stands and fertilizers.

The method with bio corridor in young stands (2nd method) would result in an increase of bio-fuels with 25 TWh per year, figure 1. That represents approximately 4 % of the total annual use of energy in Sweden (580 TWh in 2009 (energimyndigheten.se)) . The 100% bio fuel-method (3rd method) increases the harvest of bio-fuels with approximately 360 TWh. An increase of 25 TWh would replace for example most of the gas and charcoal import. An increase of 360 TWh bio-fuels would replace al coal, gas and oil-products (assumed that fuel such as ethanol, methanol or bio-diesel can be produced in an effective way out of wood raw materials)

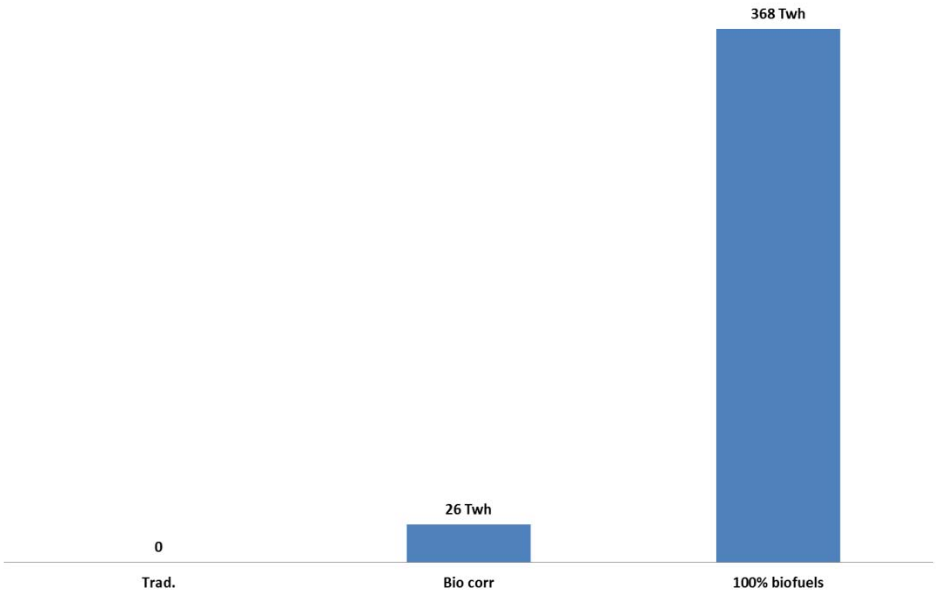

Figure 1: Increased bio-fuel volume in the alternative methods (calculations from growth functions and data from table 1 and 2). Besides this slash (branches and tops), stumps and rotted wood will be used as bio-fuels at least in the same level as today, approx 40 TWh per year.

The aim and the objective of this this analysis is to evaluate and estimate the value of the three different forest management strategies referred to above. The strategies will be evaluated from a productivity- and cost perspective as well as from an environmental perspective.

2 Methods

Obviously Swedish forestry is much more complicated than what is described in this paper. There is a lot of variation in site conditions for example in tree species and rotation period due to landscape, climate, machinery, forest owner conditions and requirements etc. To facilitate the analysis this variation has been disregarded. The three different strategies are compared regarding to a few common conditions described in table 1-3.

2.1 Three different management strategies

Traditional method (Trad)

Traditional Swedish forestry commonly involves manual planting (mechanized scarification) and motor manual pre commercial thinning approximately 10-15 years after planting. Pulpwood and saw-timber are cut in two to three thinnings (30-50 years after planting). The final operation in the cycle is final cutting when the trees are about 70 years old.

Pre-commercial thinning in corridors extracting bio fuels (Bio corr)

The first alternative to compare to the traditional management of the forest is a strategy where bio fuels will be extracted from the pre-commercial thinning 15-20 years after planting. The stands will be held dense until the thinning, with approximately twice as many stems per hectare as in traditional forest management. The harvest will be as whole trees used as bio fuel and it would be removed in corridors. After that the forest is managed in a traditional way as above. Methods similar to this have been evaluated in different studies and simulations at Skogforsk and SLU (Fogdestam 2010, Bergström 2010 and Bergkvist 2007.).

Bio fuel production in dense foreststands (100% biofuel)

The most radical strategy is the third alternative where pulpwood and timber is replaced by bio energy-production to 100 %. This alternative involves a very intense forest management with short rotation periods (approximately half the length compared to alternative 1 and 2), multiplied use of fertilizers and radical treatment of stands. This has not actually been tried in operational forestry in Sweden and neither is the short rotation period allowed in the Swedish forest law (Anon 2010a). But it is considered interesting to analyzes and compare conclusions for "what if" we do like this in Swedish forestry.

The three different methods are described in table 1. All three methods involve the same tree species (Norway spruce) and they are compared for the same rotation period (70 years). This results in two periods of 35 years each for the 100% biofuel-alternative. (Swedish forest agency)

Table 1: Operations and when they take place in the three different forest management strategies (Swedish forest agency) .

Method	Action	Year after plantation
Traditional management	Scarifying, planting	0
(Trad)	Pre commercial thinning	15
	First thinning	35
	Second thinning	50
	Final felling	70
Pre commercial thinning in corridors extracting bio fuels	Scarifying, planting	0
(Bio corr)	Pre commercial thinning in corridors	20
	Thinning	50
	Final felling	70
Bio fuel production in dense forest	Scarifying, planting	0
(100% bio fuels)	Pre commercial thinning	15
	Final felling	35
	Scarifying, planting	35
	Pre commercial thinning	50
	Final felling	70

2.2 Assumptions in the analysis

To perform the analysis some preconditions concerning for example logging costs, prices for wood, volume growth, fuel consumption etc. has to be assumed. There is as mentioned a huge number of factors that influence the analysis and of course there is a variation within each strategy. But to facilitate and make calculations and comparison possible we have defined the conditions for the analysis as in table 2 and 3. Information was collected from the statistical yearbook of the Swedish forestry 2010, The Swedish department of energy, Swedish forest agency and Swedish forestry (industry, forest companies and Skogforsk publications).

Table 2: Logging conditions (Brunberg 2011, Anon 2010b, and energimyndigheten.se)

Logging costs	
1:st thinning, SEK/m^3	150
2:nd thinning, SEK/m^3	120
Final cut, SEK/m^3	70
Final cut 100% bio fuels, SEK/MWh	50
Wood prices	
1:st thinning, SEK/m^3	350
2:nd thinning, SEK/m^3	450
Final cut, SEK/m^3	500
Final cut 100% bio fuels, SEK/MWh	120
Fuel consumption	
Scarifying, plantation l/day work	5,3
Motor manual pre commercial thinning l/day work	2
1:st thinning, l/h	1,2
2:nd thinning, l/h	1,7
Final cut, l/h	2

Table 3: General conditions (Anon 2010 b, enegimyndigheten.se)

Total $C0_2$ emissions in Sweden thousands of ton	50000
Total forested area millions of ha	23
Exports (saw-timber, pulp, paper) million of SEK	127
Exports , SEK/m^3	1500
Energy-contents in wood, MWh/m^3	2
Energy-contents in oil, MWh/ m^3	10
Price oil, SEK/l	4,5
Domestic use of saw-timber, million of m^3	16,2
Domestic use of pulp and paper millions of ton	11
Domestic use of wood products billions of SEK	93
Estimated import-cost if SEK/ha	1100
$C0_2$ emissions in diesel kg/liter	3

3 Results

3.1 Growth and possible harvesting volume

The two alternative management strategies (bio corr and 100% bio fuel) will result in higher volume growth than the reference –method (Marklund 1988). The main reason is more stems left in the young stand. More stems per hectare and thus very dens stands will result in lower average stem diameter but larger total volume per hectare. The total volume growth will increase and result in a better use of the total production capacity of the ground (Ulvcrona 2011). The total harvested tree-volume in the the 100% biofuel alternative is estimated to almost twice the tree-volume as in the reference method within the 70 years rotation period, figure 2. Calculations from growth-functions (Ulvcrona, 2011 and Marklund, 1988)

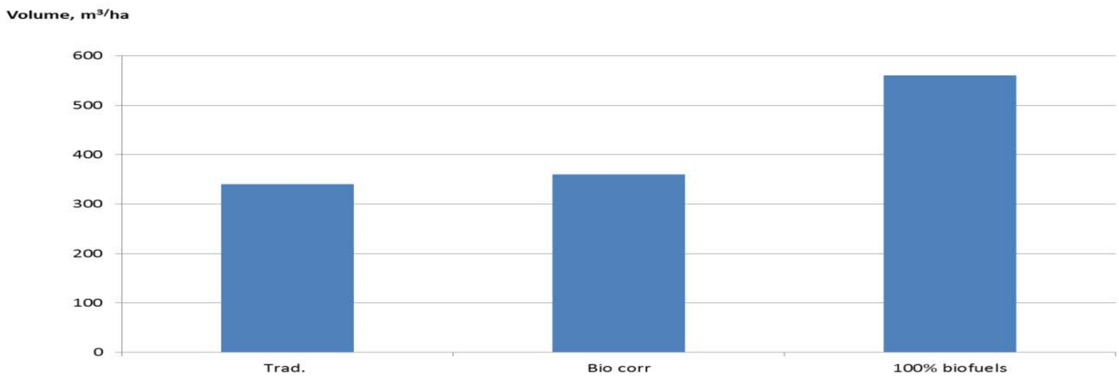

Figure 2: Total tree-volume growth and possible harvest volume during 70 years of rotation period for different management strategies.

3.2 Productivity and harvesting costs

The three different strategies involve different operations during the 70 years rotation period (see table 1). The production (m^3/hour) is different between both different strategies as well as between different actions. One important difference between the strategies is that both the “bio corr”- strategy and the “100% bio fuel”-strategy involves geometrical treatments using corridors. In the later strategy the corridors will cover 100% of the stand but the important thing is that the action will take place when the stand is 20-35 years, dense and with relatively thin average stem diameter which implies a possibility to use multi stem-technique. Geometrical thinning of young stand (for example energy-wood thinning in corridors) has been compared to traditional selective thinning in several studies, trials and simulations (Fogdestam 2010, Bergström 2009 and Bergkvist 2007). Geometrical treatment of the stand allows harvest of more than one stem at the time, ideal is to remove all stems in front of the machine or harvesting head. In studies and trials this method has resulted in 15-50 % higher production, figure 3 (Fogdestam 2010). If production is measured as “trees per hour” or “m^3 per hour” the same increase of production is expected if the site is clear-cut for energy (Ulvcrona 2011).

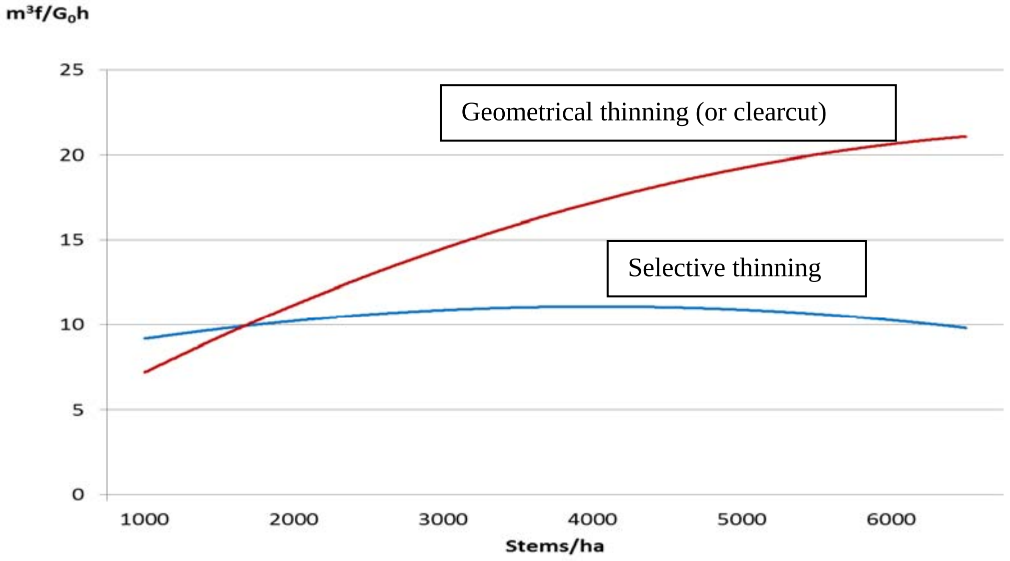

Figure 3: Production at different stand-densities in selective thinning compared to geometrical thinning (or clear-cut) where all trees are removed in front of the machine or harvesting head, average stem volume 0,03 m^3solid/stem

The problem with the "100 % bio fuel"-strategy is that time consumption per hectare will be relatively high even if multi stem technique are used, - A lot of small stems will take a long time to harvest despite method, figure 4. The total time consumtion in the "100% bio fuel"-strategy is more than twice as high compared to the two other strategies. The "bio corr"-strategy is the most effective strategy also when productivity is measured as time consumption, figure 4.

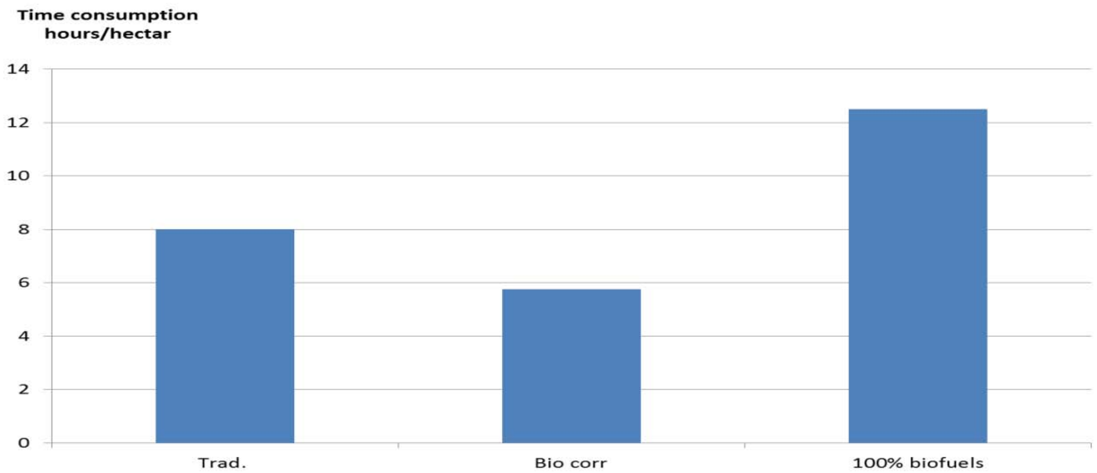

Figure 4: Total time consumption per hectare in the three different management strategies

3.3 Fuel consumption and CO2 emissions

A low production rate implies the energy use as well. Figure 5 describe the estimated consumption of fuel and emission of CO2 for each strategy and for all actions during the 70-year rotation period. The high consumption of fuel in the "100% bio-fuel"- method is connected to the low production. The production rate remains low for all actions in the rotation –period, the reason for that is a low average stem diameter in all harvesting actions (many small stems take a long time to harvest). Low production results in a higher fuel consumption per m3. The consumption of fuel (and thereby also the C02 emission) is almost twice has high in the 100% bio-fuel method than in the traditional method, figure 5. Bio-fuel in corridors is on the other hand slightly more energy-efficient than the traditional method. This is connected to the higher production rate in that method, figure 5.

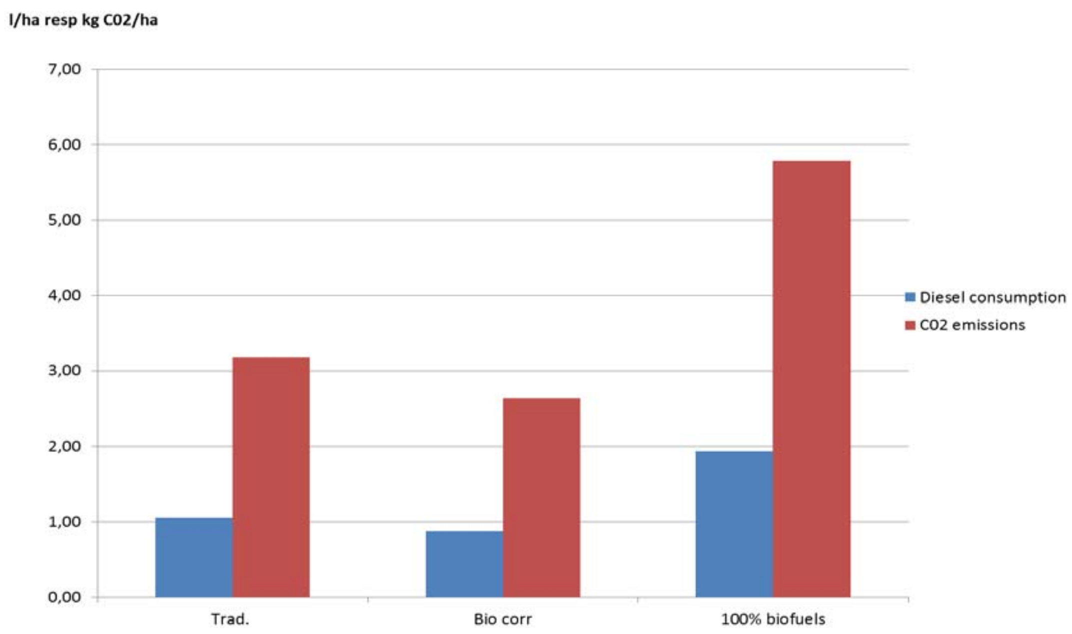

Figure 5: Consumption of fuel and $C0_2$ emissions allocated on the 70 year rotation period. Blue columns represent fuel and red columns represent $C0_2$ emissions

3.4 Net value for the forest owner

A cost –revenue analysis, with presents values for each operation and income, shows a distinct profit in the strategy with harvest of biofuels in corridors, figure 6. The key is high production rate, low energy use per m^3 and an early income from biofuels. The "100% bio-fuel"- method gains from the short rotation period and thereby a big income early, figure 6. But this is not enough to cover the higher harvesting cost, see figure 5.

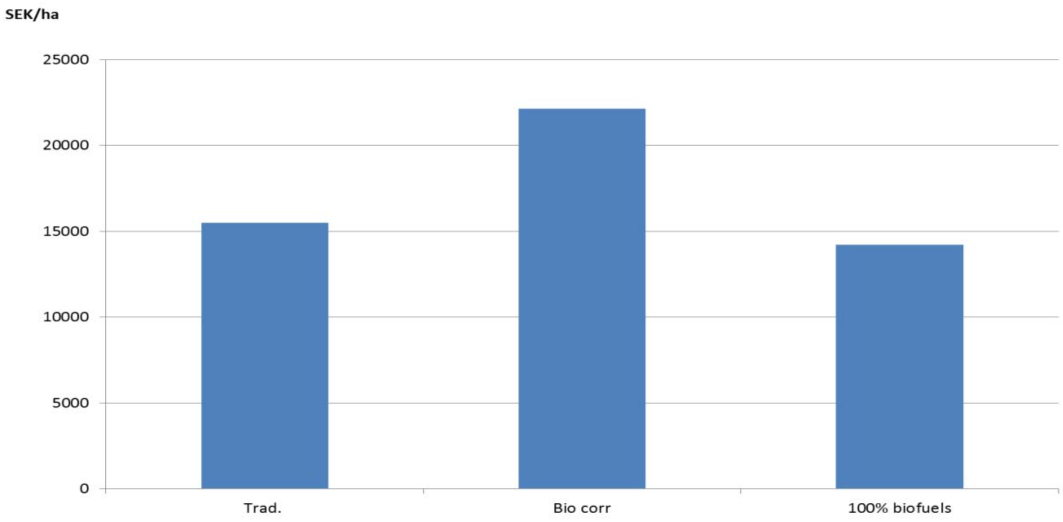

Figure 6: Net present value per year and hectare for each forest management strategy.

4 Discussion

With the goal to eventually be independent of fossil fuels Sweden and Swedish forestry needs to increase the annual harvest of forest fuels. The most widely spread forest fuel assortment is branches and tops of the trees. The volume of residues could increase but the material is also needed to increase the bearing-capacity of the ground. In wet and semi wet areas almost all the residue volume is needed to drive on. Stump harvest is practice to a very little extent in Swedish forestry but there are problems to increase that volume in present forestry due to regulations in FSC and PEFC-certification. This leaves us with the possibility to increase the volume of forest-fuel in young stands. The analysis in this paper shows two alternative ways to increase the volume of forest-fuel in young stands. Either by holding the stands denser with more stems per hectare and harvest forest-fuel at the first thinning, or by leaving the stand intact until a very early final-cut.

In the “100% biofuel” strategy all saw-timber pulp and paper will be replaced with energy assortments. The consequence of that is either that all prepared volume of saw logs and paper will be imported which would result in closure of saw- pulp-and paper industry. Alternatively all raw material would be imported to supply the industry which probably would result in more expensive products. Irrespective of what, it would have big effect on the Swedish economy. Since the strategy would lead to a big reduction in the import of fossil energy some of the lost incomes from export and increased import costs would be compensated. There is obviously an environmental gain in being close to self-supporting in renewable energy sources, but if the domestic use of paper and saw-timber stays intact the production will take place somewhere else where the environmental consequences might be higher.

5 Conclusions

In this analysis the method with dense young forests and harvest of bio-fuel in corridors increases the productivity in Swedish forestry since wood production, value of forest land and logging efficiency increases while the fuel consumption decreases as well as the CO_2 emissions .

The method with 100% biofuel harvest maximizes the use of renewable energy. But with the type of machinery in present Swedish forestry the productivity will decrease leading to lower profit, lower state economy and higher environmental effects.

The environmental consequences might even be higher when the production of wood-products is moved somewere else. The method with dense young forest and corridor thinning seems to be a good alternative to the traditional management of forests in Sweden

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