# GUIDELINES FOR ECONOMICALLY RATIONAL AND COORDINATED DYNAMIC DEVELOPMENT OF THE FOREST AND BIO ENERGY SECTORS WITH CO2 CONSTRAINTS

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ABSTRACT: This study focuses on economic optimization of the total present value of the forest and bioenergy sectors in a region. Sweden is an example, a country with large forest resources. The forest stock has been strongly growing during 90 years. The harvest level is and has been much lower than the growth. A general mathematical proof is given that explicitly shows that the optimal harvest level and the total capacity level in the forest and bio energy sectors should be strongly increased as soon as possible. New interactive optimization software has been developed, that is possible to use via Internet. The harvest level and the total capacity in the forest and bioenergy sectors should be increased by approximately 50% in order to optimize the total present value. The optimal dynamic time path of the forest resource is calculated and described. The importance and consequences of alternative levels of growth in new plantations via improved plant material and other forest anagement methods are demonstrated. Increased forest harvesting and new plantations, in combination with energy production, $CO_2$ separation and $CO_2$ storage, will reduce the $CO_2$ contents of the atmosphere. Any future $CO_2$ level can be reached.
Keywords: Bio-energy strategy, CO2 balance, Forestry, Economic investments

## 1 INTRODUCTION

Sweden has large forest resources. The stock level has never, during the period when this has been estimated, been larger than in 2008. The main media image of the state of the forest is quite different. The board of forestry sends warnings to the public with the message that the harvest level is too high and that such a harvest level will not lead to sustainable forestry. This is highly surprising, since the harvest level is much lower than the growth level and the stock level constantly increases.

Sweden is a nation with an economically important forest sector. The Swedish forest industry gives considerable export revenues to Sweden, almost 11 billion EURO per year. The forest sector also contributes to the level of employment, in particular in regions with low employment levels.

Large parts of the forest industry mills will be closed down during 2008 with the motivation that sufficient raw material does not exist, even though the forest growth very much exceeds the harvest level.

The energy industry, in particular CHP, combined heat and power plants, is rapidly expanding in Sweden, and the energy raw material potential of the Swedish forests is under investigation. Compare Buskhe [1].

In this situation, it is of central importance to investigate and determine how the most rational and coordinated development of forest management, forest industry and energy industry can be found and optimized. For this reason, this study focuses on "Economically optimal dynamic development of the forest resource, forest products industry and forest raw material based energy industry in Sweden" during the following decades.

The highly detailed official statistics including information concerning the forest resource has been used to define the initial state and dynamics of the forest in Sweden. The capacity investments of the forest products and forest raw material based energy industries are included as endogenous variables in the analysis.

## 2 RATIONAL STRATEGIES UNDER ALTERNATIVE ASSUMPTIONS

The methods described in the later sections of this text have been applied to the case of Sweden.

It turns out that there are large options to strongly increase the industrial use of raw material from the forest, including timber, pulp wood and other assortments, irrespective of how this raw material is distributed between the forest products industry and the forest raw material based energy industry.

Sensitivity analyses of different kinds have been performed. The reader is encouraged to investigate how the rationalities of possible dynamic expansion plans are affected by alternative assumptions concerning the different parameters. The reader may use the two versions of interactive software that have been developed and input any figures that are considered relevant concerning forest stock and growth, stock level constraints, prices, market rates of interest etc.. The solutions are almost instantly obtained from the internet.

## 3 ECONOMIC OPTIMIZATION FROM DIFFERENT PERSPECTIVES

We may, with alternative definitions and methods, investigate the system that includes the three "sectors" Swedish forestry (SF), the Swedish forest products industry (SFPI) and the forest raw material based energy industry (FRMBEI). The ambition is to find the dynamic strategy for the management of this system that leads to the best possible total economic surplus (present value).

It should always be of interest to generate the best possible total surplus. The way that this total surplus, in a second stage, is distributed between the parties, is an issue that is not treated in this study.

Of course, it is possible to optimize the strategies of the three sectors individually, one at a time. However, it is quite clear that these sectors have strong connections to each other.

If we, for instance, from the point of view of SF, consider the industrial capacities of SFPI and FRMBEI as exogenous variables, and try to optimize the activities of SF, we will almost surely obtain a solution that is feasible and optimal to SF. We may denote this solution SF1.

We may also independendly optimize the activities of SFPI and FRMBEI, using the assumption that the activities of SF are exogenous.

When we plan the activities of SFPI, we assume that the activities of FRMBEI are exogenous and when we plan the activities of FRMBEI, we assume that the activities of SFPI are also exogenous. We will then get the solutions SFPI1 and FRMBEI1.

However: SF1, SFPI1 and FRMBEI1 will generally not, taken together, give the best possible total economic result, since these solutions have been calculated without considering the option of rational dynamic coordination. For instance, there is not reason to increase harvesting in SF in case the capacities of SFPI and FRMBEI are considered to be constant. In the same fashion, there is no reason for SFPI and/or FRMBEI to increase the capacities in case they believe that the harvesting of SF is constant. If dynamic harvesting and capacity expansion can be simultaneously optimized, much better total results are possible to obtain. This shows that rational coordination is essential to a system of this kind. In the appendix reference and in the internet software references, you may find examples of economic optimization of systems where forestry, logistics and industry are simultaneously optimized.

Below, we will investigate how we may describe the dynamic options of the three sectors using mathematical models. We will find that we may calculate a combination of forest harvesting and replanting with capacity investments in different kinds of forest raw material based industry that maximize the total economic result. The derivations are made with analytical and numerical methods in different resolution.

It is quite possible to increase the level of detail, almost without limit. In this report, however, the ambition is to make it possible for the reader to get a comlpete overview and to understand all relevant and important assumptions and derivations. This would not be possible with derivations in high resolution. Furthermore, the author is convinced that a severe problem with many investigations is that the level of detail is too high. In Sweden we say that “We can not see the forest because there are too many trees”. Here, the important thing is to see how we may combine forest management with the other sectors. The details of the forests are not critical to this aim.

The analysis will be made from three different different perspectives:

- Raw material perspective
- Total Perspective I
- Total Perspective II

## 4 OPERATIONS RESEARCH FROM A RAW MATERIAL PERSPECTIVE

The article by Faustmann [2] is usually considered to be the foundation of the discipline of forest economics. This research area has, as most other sciences, developed over time. Compare for instance Johansson and Löfgren [3] and Lohmander [4].

A considerable part of the forest economics theory is concentrated to the economically optimal decisions within a particular forest stand. In these studies, prices, harvest costs etc. are considered to be exogenous. The optimal time to make the final felling and the years and volumes of the partial harvests, thinnings, are derived, with consideration of the particular conditions of relevance to the individual forest stand. Of course, the decision problems of particular forest stands may be of relevance to many owners of small forest estates. Such forest owners may often regard most things as exogenous variables.

From a typical raw material perspective, the most important question usually is the following: How can we optimize the present value of the presently existing forest stand and the land that this stand is growing on?

In the older forest stands, that generally represent the majority of the economic value of a forest property, the only remaining question is this:

When should I make the final felling in order to maximize the present value of the harvest plus the present value of the released forest land?

### 4.1 Observations from a raw material perspective:

A large part of the Swedish forest should be instantly harvested, even if the real rate of interest in alternative investments is not higher than 3%.

If the relevant real rate of interest is higher than 3%, even more should be instantly harvested.

In case the growth in future plantations increases, the value of the land that is released after harvest increases. Then, it is optimal to harvest the initially existing forest stand earlier.

In Sweden, the forest act and connected regulations imply forest management constraints. There are detailed rules that regulate most decisions in forestry. In a particular stand, a final felling is not allowed before some specified age of the trees has been obtained. Furthermore, you are not allowed to make a partial harvest, a thinning, such that the stock level after harvest is below some specified limit. You can not select any species that you want in a plantation. You can not harvest any area that you want and there are constraints that regulate the total harvest area during a particular period.

No official documents with derivations exist that show that these forest management regulations are economically motivated. In many cases, it is possible to show that the constraints dramatically decrease the possible economic results from forestry.

## 5 OPERATIONS RESEARCH FROM TOTAL PERSPECTIVE I

Within "Total Perspective I", the problem is defined this way:

We simultaneously consider forest harvesting, forest replanting, industrial use of forest raw material (in the forest products industry and in the forest raw material based energy industry) and dynamic industrial capacity planning.

The forest state and the industrial capacities have certain initial states, "right now". We introduce a time axis. Time zero represents the present time. The stock level and the growth of the existing forest are exogenous parameters since they have been determined by earlier decisions and actions.

We consider the option to adjust (normally expand) the industrial capacity. Expansion takes time. Planning, the legal processes and construction take time. If we make the decision at time $t0 = 0$, we may start using the capacity at time t1. In Sweden, a typical value of $t1 = 5$ (years).

The capacity adjustment (increase) that we determine is a decision variable. We assume that the capacity will be fully utilized, which means that the harvest is simultaneously determined.

When we determine the capacity expansion, we simultaneously consider the initial forest state and the future forest development, which is affected by the future harvest, which in turn is affected by the capacity investment level. The ambition is that the decisions in combination will be selected such that the best total economic result is obtained.

We instantly realize that if we expand the industrial capacity very much, we may have to harvest more than the growth of the forest during the period when the new capacity will exist and be used. As a consequence, the stock level will decrease over time. Some other years, it is possible that the growth is higher than the harvest. Then, the stock level increases.

We must determine the lowest acceptable stock level. When we know the lowest acceptable stock level, we may calculate the length of the time when we can use the new industrial capacity that we, maybe, build, before this industrial capacity possibly has to get raw material supply from some other region, be moved to some other region or be closed down. The point in time when we reach the lowest acceptable stock level is denoted t2.

During the time interval from t0 to t1, we harvest the same volume per year as at t0. This volume, denoted h0, is used in the initially existing industry.

In the time interval from t1 to t2, we harvest what we need in order to use the industrial capacity that will exist during that time interval. The harvest level during this time interval is denoted h1.

From time t2 (and later), the harvest level is denoted h2. h2 is exactly the same as the forest growth. As a result, all activities from time t2 are sustainable and can continue for ever.

### 5.1 Some conservative results:

As one alternative, we may investigate what we should do if we are extremely restrictive and base our strategy on the following artificial constraints: We do not accept, at any point in time, to let the forest stock level be reduced below the extremely high level of the year 2008. Furthermore, we do not accept to assume that the growth in new plantations will be higher than in the old forest stands. (This is simply not true, since genetic improvement programmes have been in action for a long time and new plants really grow much better than plants in the past. Still, just to be completely sure that we do not harvest too much, we make this extreme assumption in this case.)

Then, with this extreme stock level constraint and this extreme growth assumption: What should we do? Well, even then, we may harvest 112 million cubic metres per year during 21 years. This represents a harvest increase of 30% in relation to the harvest during the period 2000 - 2008! Even then, the forest products industry and/or the forest raw material based energy industry should be strongly expanded, as soon as possible. In the long run, according to this very conservative analysis alternative, the yearly harvest has to be the same as the yearly growth, which is 106 million cubic metres. Even this long term steady state level represents harvesting and industrial use of 23% more than before.

## 6 OPERATIONS RESEARCH FROM TOTAL PERSPECTIVE II

Total Perspective II corresponds to Total Perspective I in most ways. However, some differences are these:

In Total Perspective II, the derivations are based on the fact that the growth in the forests that are planted after the harvest of the old forests, may be different. In most cases, it can be shown that new plants will grow much better than plants from earlier forest stands. In some cases, it is also possible to replant the forest land with other species. The optimal intensities of future forest management activities of different kinds may also be quite different from the traditions. Now, the energy industry is expanding. The relative values of different wood dimensions, species, qualities etc. are quite different from a forest energy perspective in relation from a traditional forest products industry perspective. Maybe the species distribution, the number of seedlings per hectare, the thinning methods and the age of the final fellings should be modified? It would be very surprising if the earlier standard methods would still be optimal in this new situation.

Since the area that is replanted with more rapidly growing plants increases over time, the growth also increases. As a result, the stock level curves describe strictly convex functions of time during every time interval when the harvest level is constant.

With data from Sweden, it was possible to derive these results:

Even if we are not willing to reduce the forest stock level below the level of the year 1980, it is rational to strongly invest in industrial capacity and increase harvesting as soon as possible.

In one "standard version" of the analysis, it was assumed that the growth in new plantations increases by 19% in relation to the earlier growth level. This is a "conservative assumption" since several studies show that the growth can improve much more than that with intensive production methods. Still, the analysis shows that we should increase harvesting very much during a long time period. For instance, we may harvest 136 million cubic metres during a 20 years period. From the year 2000 to 2008, the average harvest level has been close to 86 million cubic metres per year. Hence, the harvest level increases by 50 million cubic metres, or by 58%! This period starts five years from now, 2013. 25 years from now, in 2033, we will have 2.6 billion cubic metres in the forest stock, which is the same as we had in the year 1980.

The total economic value, the present value of the forest resource, the forest products industry and the forest raw material based energy industry, strongly increases if we follow this strategy.

## 7 CO2, THE CLIMATE AND OPTIMAL FOREST MANAGEMENT

We may ask ourselves how we should take the CO2 issue into account when we determine the optimal way to manage the forests and combine the harvests with industrial capacity planning and production. A growing forest captures and stores CO2 from the atmosphere. Therefore, if we think that it is valuable to reduce the CO2 contents of the atmosphere, it is valuable to let the stock of the forest grow large and store large amounts of CO2. CO2 is one of the most important "greenhouse gases" and, though fundamental physical processes, it contributes to global warming.

However, trees do not grow for ever. Sooner or later, the growth level is reduced, because the age of the trees becomes too high and the competition between neighbour trees too strong for continued growth. Furthermore, at some age, trees die, and once again release the stored CO2 to the atmosphere. Occationally, many old trees die at the same time, for instance when we have storms. Then, a lot of CO2 is simultaneously released.

The expected average stock level stabilizes at some level. As a consequence, in the long run, the forests can not store more CO2 than some maximum level that we may denote CO2Formax.

Let us define the present point in time as year 0. Assume that we start with bare land. We plant seedlings and we obtain a growing forest. After T years, we reach the CO2 stock level S. S < CO2Formax.

(In case we would let the forest grow for ever, we would approach, and possibly reach, the stock level CO2Formax.)

At time T, we harvest the forest stand. We use 50% of the wood for energy and 50% for traditional forest industry products.

When we produce energy by burning the biomass, we use the technology denoted CCS, CO2 capture and storage. We store the CO2 permanently in a reliable way, far below the surface of the earth, according to some of the methods described by IPCC, International Panel on Climatic Change.

The part of the biomass that is not used to produce energy, may be used to produce timber houses, paper and other products. Some of these other products, such as timber houses, will store the CO2 for a considerable time, maybe centuries. Other products, such as paper, may be recycled a number of times and eventually burnt in order to produce energy. In the long run, most products produced from the forest raw material may burn and produce energy. Then, the CCS technology can once again be used to store the CO2 permanently, below the surface of the earth.

As a matter of fact, we may conclude that the total amount of CO2 that may be captured from the atmosphere and permanently stored is much higher if we, in a repeated sequence, harvest the forest (for instance at stock level S), use some (let us say 50 %) of the biomass for instant energy production, capture and store the CO2 and replant the area again.

This way, we may, in the long run capture and store any amount of CO2 from the atmosphere! This way, we do not only reduce the new emissions of CO2 but we really make sure that the CO2 level of the atmosphere is reduced!

If you just leave the forest for ever, without harvesting, you will not be able to capture and store more than CO2Formax.

In the long run, if you use the suggested sequence of harvests and CCS, then the permanently stored amount of CO2 is, on average, S/T per year.

The stock of permanently stored CO2 is S*N where N is an integer. N is the number of harvests and CCS cycles that have already taken place.

The conclusion is the following: If we are interested to reduce reduce global warming, one way to do this is to reduce the CO2 contents of the atmosphere. In that case, we should not let the forests grow too long. We should sequentially harvest and replant the area, using some part of the biomass for energy in combination with the CCS technology. This way, we can reach any future level of CO2 in the atmosphere that we may desire.

## 8 REFERENCES


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## 9 APPENDIX

An analytical and numerical appendix of relevance to this text is found on pages 35 – 50 in this document: http://www.lohmander.com/EF2008/EF2008Lohmander.pdf

## 10 SOFTWARE ON THE INTERNET

Software for Total Perspective I:
http://www.lohmander.com/ef2008/ef2008.htm
Software for Total Perspective II:
http://www.lohmander.com/ef2008/efchange2008.htm
Software for illustration of the CO2 and forest management issue in combination with CCS technology:
http://www.lohmander.com/co2ill2/co2ill2.htm
Software with connected information and references:
http://www.Lohmander.com

## 9 ACKNOWLEDGEMENTS

My thanks go to E.ON Sweden, for economic support to the research project “Economic forest production with consideration of the forest and energy industries”.

## 10 OBSERVATION

A misprint was corrected 2008-09-03.