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Logistics and pretreatment of forest biomass

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ABSTRACT

In large regions of the world, biomass is a very important source of energy. The global bioenergy market based on forest biomass is growing rapidly. About 92 % of the bioenergy in Sweden comes from forests. Biomass from forests is not homogenous. The locations, transport distances, and transport methods, can differ very much and the industries that need biomass as input prefer raw materials with different properties. In general, the economically optimal forest biomass and pretreatment methods have to be determined with consideration of the relevant objective function, constraints and information structure. The aim of this paper is to investigate typical cases and to derive general rules for optimal combinations of forest biomass and pretreatment methods in alternative situations. Mathematical models are defined, representing different versions of the forest biomass logistics, upgrading and pretreatment optimization problems. General rules of optimal decisions, based on these models, are derived and suggestions for future research and applications are given.

Keywords: *Forest, Biomass, Bioenergy, Pretreatment, Upgrading, Logistics.*

INTRODUCTION

In large regions of the world, biomass is a very important source of energy. SVEBIO (2011) writes that bioenergy now is "larger than oil" in Sweden. Bioenergy represents the largest share, 32%, of domestic energy consumption in Sweden. Based on the information from Gyllin (2011), about 92 % of the bioenergy in Sweden comes from the forests. Borgman (2011) claims that the global bioenergy market based on forest biomass is growing rapidly. The statistics are published by the Swedish Forest Agency (2011). Borgman (2011) writes that the forest biomass demand increases in Europe and that Russia is expanding the wood pellets production to be able to increase the export volumes to Europe. The former prime minister of Sweden, Göran Persson, is the chair of the board of Sveaskog, the largest forest owning company in Sweden. According to Borgman (2011), Persson explains that Sveaskog now is investigating options to increase the export of forest biofuels to Germany and England. These countries need large amounts of renewable energy in order to satisfy their political goals. EU (European Union) has the target of having at least 20% renewable energy in the year 2020. In order to export forest biofuels from Sweden to Germany and England in an economically rational way, it is important to reduce the water content and to improve the efficiency of the logistic solutions. For these reasons, Sveaskog is interested in different kinds of upgrading, such as torrefication, pyrolysis and gasification. Sveaskog is also one of the owners of a company that produces biodiesel from the tree species of Scots pine. According to Borgman (2011), several of the coal power stations in Germany, owned by the Swedish energy company Vattenfall, will start using pellets from Norway, mixed with coal. The energy content of these pellets, 15 gigajoule per cubic metre, is higher than that in standard pellets (11 gigajoule per cubic metre). For this reason, it has been found that up to 20%, or maybe even more, of the coal can be replaced in these power stations. The special pellets upgrading method is described in Freepatentsonline (2009). Another company, Swedish Biofuels (2011)], writes that they develop motor fuels produced from grain crops or cellulosic raw material, including wood. These fuels are completely identical to petroleum derived motor fuels. These motor fuels are suitable for operation in conventional, standard engines. The produced fuels are alternatives to gasoline, diesel and jet fuels. Biomass from forests is not homogenous. The locations, transport distances and transport methods, can differ very much and the industries that need biomass as input prefer raw materials with different properties. In general, the economically optimal forest biomass and pretreatment methods have to be determined with consideration of the relevant objective function, constraints and information structure. The ambition of this paper is to investigate typical cases and to derive general rules for optimal combinations of forest biomass and pretreatment methods.

Mosier et al (2005) study pretreatment, which is an important tool for practical cellulose conversion processes. They explain that pretreatment is required to alter the structure of cellulosic biomass to make cellulose more accessible to the enzymes that convert the carbohydrate polymers into fermentable sugars. Mosier et al (2005) stress that pretreatment results must be balanced against their impact on the cost of the downstream processing steps and the trade-off between operating costs, capital costs and biomass costs. The author of this chapter would like to add that pretreatment also may change transport costs and the types of logistic solutions that are the most cost efficient alternatives.

Wyman et al (2007) report that the different stages of pretreatment, represent about 39% of the total cost, in cellulosic ethanol production. The first stage of pretreatment, where biomass and chemicals are transformed to dissolved sugars, oligomers and lignin, and solids such as cellolose, hemicellulose and lignin, represents about 18% of the total cost.

Ahring and Westermann (2007) write that large scale transformation of biomass to more versatile energy carriers has most commonly been focused on one product such as ethanol or methane. They also state that this approach is not optimal if the energy content of the biomass is supposed to be exploited maximally. For this resaon, they describe and analyse multiple fuel production systems. They report that current pretreatment methods contribute to 30-40% of the total cost of bioethanol production from lignocellulosic biomass. Their analysis is methodologically interesting since they study optimal combinations of several decision variables, such as temperature, pressure, amount of oxygen addition and residence time.

This chapter is connected to some of the ideas presented by Ahring and Westermann (2007) in the sence that it will investigate optimization problems in which it is important to deal with several products simulatenously. However, the chapter will not only study the problems of multiple fuels but try to cover the general forest biomass problems that also has to consider production in CHP (Combind heat and power) plants, CHPP (Combined heat, power and pellets) plants, other forest industry product mills and alternative forest harvesting and management decisions. Most forest biomass resources on our planet are forests with trees of several species and different properties, locations and dimensions. Furthermore, in this chapter, we are focusing on optimization of the total economic result, which usually means that the optimal solutions are different from solutions obtained from problems where the objective is to maximize energy content utilization.

Kumar and Murthy (2011) performed a comprehensive techno-economic analysis for conversion of cellulosic feedstock to ethanol, using some of the common pretreatment technologies: dilute acid, dilute alkai, hot water and steam explosion. They write that a detalied process model which includes all unit operations from biomass handling to ethanol distillation can be helpful to perform the economic analysis of the whole process on a commercial scale. The author of this chapter strongly agrees with the ideas put forward by Kumar and Murthy (2011) and would like to stress that such models should include all relevant and connected processes, not just ethanol related parts of the forest biomass system. From the forest production point of view, ethanol is an important final product, but not the only one. Forest production is a typical case of joint production. Timber, pulpwood and energy assortments sent to CHP and CHPP, and ethanol plants are usually produced simultaneously, in the same forest stands, and the economic management of these assortements have strong links with respect to costs. Such complete system optimization models should be developed in the future and hopefully the general observations put forward in this chapter can be useful in this process. Kumar and Murthy (2011) make the assumption that the price of feedstock and cellulose enzymes was \$50/metric ton. They also study the sensitivity of the optimal solution to this assumption, which is highly relevant. The author of this chapter would like to stress that this is an assumption that strongly influences the optimal solutions and that \$50/metric tons is a very special case, that depends on a large number of conditions that can be very different in different locations. Kumar and Murthy (2011) use a cost function for new equipment with an exponential scaling equation. Unfortunately, the value of the exponent was not found in the article. With this functional form, economies or diseconomies of scale are easily studied. Such topics are also discussed in this chapter. Kumar and Murthy (2011) finally report that the ethanol production costs for plants using dilute acid, dilute alcali, hot water and steam explosion pretreatment processes were \$ 0.84, \$ 0.89, \$ 0.81 and \$ 0.86 per liter of ethanol, respectively. Biomass (46.21% to 56.22%) and enzymes (34.3% to 40.76%) were major contributors to total raw material cost.

Lynd, Elander and Wyman (1996) widen the scope of the biofuel analysis by also explicitly considering electricity generation. They write that combining advanced ethanol production technology with advanced gas turbine-based power generation is a promising direction for future analysis and may offer still further cost reductions and efficiency increases. The authors explicitly analyse the relationship between crop production and transport distances. They find that, with the base case technology, pretreatment represents 32.7% of the total processing cost and 17.2% of the total overall cost. In the "best parameter case", pretreatment represents 63.3% of the total processing cost and 10.1% of the total overall cost. According to the biomass ethanol cost and selling price breakdown, with advanced technology, pretreatment represents 65.5% of the total processing cost.

Let us conclude this section with the following observation: Pretreatment costs are often considerable. Hence, it is economically important to optimize pretreatment and linked activities in the supply chains.

MATERIALS AND METHODS

Optimal pretreatment and upgrading

The optimal pretreatment and upgrading problem can be defined in several ways. Consider upgrading as a decision variable, u . Often, it is more interesting to consider the option to upgrade the biomass in several parts of the supply chain. Then, there are several upgrading decision variables: $u_1, u_2, ..., u_m$.

Upgrading can be defined as a continuous decision variable, for instance some level of heat energy applied per ton of biomass, in order to reduce the contents of water. In other applications, upgrading can be defined as a discrete variable, where each alternative value represents some specific type of pretreatment or combination of specific pretreatment methods.

In every case, it is important that the relevant upgrading alternatives and methods are included as decision variables in the optimization problem. Furthermore, upgrading is not interesting in itself. Upgrading usually is a rational activity because it influences cost and revenues in the total problem under consideration. Upgrading usually influences the weight and the energy contents per weight unit. Furthermore, it often reduces the total energy contents of the biomass and upgrading is usually not costless. Special equipment may be needed. The costs of upgrading are usually different in different locations and there may be economies of scale.

If the level and spatial distribution of upgrading changes, it usually influences the optimal transport methods, transport equipment and logistic solutions, T , and infrastructure, I .

It is usually rational to select different decisions T_i and I_i in different parts of the total supply chain. Let us define $C_i(.)$ as the cost function in one part, i, of the supply chain, and C as the total cost in the supply chain.

$$\min C = C_1(u_1,T_1,I_1) + C_2(u_1,u_2,T_2,I_2) + \ldots + C_m(u_1,u_2,\ldots,u_m,T_m,I_m) \quad (1)$$

Note that the costs in later parts of the supply chain typically are functions of upgrading activitites in all earlier parts of the supply chain.

Generally, it is more relevant to the total decision problem to maximize the total profit of all activities in the supply chain, including not only the earlier mentioned activities and costs but also the profits in the different industrial plants. Since forest biomass is one of the many possible outputs from forest production, and other outputs are timber and pulpwood, plants of relevance to the forest biomass upgrading problems include CHP (combined heat and power), CHPP (combined heat, power and pellets), chemical plants of several types, sawmills and pulp- and paper- mills. Pretreatments and upgrading of different kinds in different parts of the supply chain influence the profits in these different industrial plants. We define $R_j(u_1,u_2,\ldots,u_n,d_j)$ as the profit in plant j and d_j as the decision(s) in plant j.

Typically, we want to maximize the total profit in the supply chain, Π.

$$\max \Pi = -C(.) + R_1(u_1,u_2,\ldots,u_n,d_1) + R_2(u_1,u_2,\ldots,u_n,d_2) + \ldots + R_n(u_1,u_2,\ldots,u_n,d_n) \quad (2)$$

There may be constraints of several kinds in the supply chains. These are usually functions of locations, available infrastructure, national and regional laws and regulations. In the following sections, a set of special and typical cases will be investigated.

RESULTS

Optimal pretreatment or upgrading at the source

Consider a pretreatment or upgrading problem of the following kind:

Biomass is upgraded at the source (in the forest region). u_1 is a continuous decision variable, for instance representing the amount of heat used per biomass unit. $C_1(u_1)V_0$ is the upgrading cost. $C_1(u_1)$ is a strictly increasing and convex function of u_1. V_0 is the initial weight of raw biomass, with some water. $W(u_1)$ is a decreasing and strictly convex function of u_1. $0 < W(u_1) < 1$. $W(u_1)V_0$ is the weight of the upgraded biomass. $pX(u_1)$ is the economic value per weight unit of the upgraded biomass at the plant. $X(u_1)$ is a strictly increasing function of u_1. $0 < X(u_1)$. Hence, $pX(u_1)W(u_1)V_0$ is the economic value of the upgraded biomass when it reaches the plant. Clearly, the pretreatment, or upgrading, will in this case not only affect the value of the biomass at the mill, $pX(u_1)W(u_1)V_0$, but also the transport cost, $tW(u_1)V_0$, where t is the transport cost per weight unit, from the source to the mill.

The optimization problem can be stated as a profit maximization problem with one decision variable, u_1:

$$\max \Pi = -C_1(u_1)V_0 - tW(u_1)V_0 + pX(u_1)W(u_1)V_0 \quad (3)$$

Let us define π as $\frac{\Pi}{V_0}$. Then, the optimization problem becomes:

$$\max \pi = -C_1(u_1) - tW(u_1) + pX(u_1)W(u_1) \quad (4)$$

The first order optimum condition is:

$$\frac{d\pi}{du_1} = -\frac{dC_1(u_1)}{du_1} - t\frac{dW(u_1)}{du_1} + p\frac{dX(u_1)}{du_1}W(u_1) + pX(u_1)\frac{dW(u_1)}{du_1} = 0 \quad (5)$$

The second order derivative of the objective function with respect to the decision variable is:

$$\frac{d^2\pi}{du_1^2} = -\frac{d^2C_1(u_1)}{du_1^2} - t\frac{d^2W(u_1)}{du_1^2} + p\frac{d^2X(u_1)}{du_1^2}W(u_1) + p\frac{dX(u_1)}{du_1}\frac{dW(u_1)}{du_1} + p\frac{dX(u_1)}{du_1}\frac{dW(u_1)}{du_1} + pX(u_1)\frac{d^2W(u_1)}{du_1^2} \quad (6)$$

If we have a unique maximum, $\frac{d^2\pi}{du_1^2} < 0$.

Without more detailed information about the functions and parameters, it is not possible to determine if the second order maximum condition is fulfilled.

Now, we make the assumption that we have a unique maximum.

$$\left(\frac{d\pi}{du_1} = 0\right) \Rightarrow$$

$$-t\frac{dW(u_1)}{du_1} + p\frac{dX(u_1)}{du_1}W(u_1) = \frac{dC_1(u_1)}{du_1} - pX(u_1)\frac{dW(u_1)}{du_1} \quad (7)$$

This equation can be given the following interpretation: In optimum, the marginal revenue should equal the marginal cost. In this particular situation, this interpretation of the result can be made:

$$A_1 = -t\frac{dW(u_1)}{du_1} \quad (8)$$

$$A_2 = p\frac{dX(u_1)}{du_1}W(u_1) \quad (9)$$

$$A_3 = \frac{dC_1(u_1)}{du_1} \quad (10)$$

$$A_4 = -pX(u_1)\frac{dW(u_1)}{du_1} \quad (11)$$

$$A_1 + A_2 = A_3 + A_4 \quad (12)$$

The "marginal revenue" can be interpreted as: "The marginal reduction of the transport cost because of weight reduction via upgrading, A_1, plus the increase of the marginal revenue via upgrading thanks to higher unit value at the mill, A_2".

The marginal cost can be interpreted this way: "The marginal cost of upgrading at the source, A_3, plus the marginal value reduction via upgrading caused by weight reduction, A_4."

Optimal combinations of pretreatments

Now, consider an upgrading problem of the following kind:

$$\max \pi(u_1,u_2) = -C_1(u_1) - tW(u_1) - C_2(u_2) + pX(u_1+u_2)W(u_1+u_2)$$
(13)

u_2 is the level of upgrading at the mill and $C_2(u_2)$ is the cost of upgrading at the mill.

Special case:

Let us make the assumtion that the total level of upgrading, before the raw material enters the mill, is a constant, U_0.

$$u_1 + u_2 = U_0 \quad (U_0 \; exogenous) \quad (14)$$

$$u_2 = U_0 - u_1 \quad (15)$$

$$\max \pi(u_1, U_0 - u_1) = -C_1(u_1) - tW(u_1)$$
$$-C_2(U_0 - u_1) + pX(U_0)W(U_0) \quad (16)$$

$$\max \pi(u_1) = -C_1(u_1) - tW(u_1) - C_2(U_0 - u_1) + k \quad (17)$$

$$\frac{d\pi}{du_1} = -\frac{dC_1(u_1)}{du_1} - t\frac{dW(u_1)}{du_1} + \frac{dC_2(U_0-u_1)}{du_2} = 0 \quad (18)$$

$$\frac{dC_1(u_1)}{du_1} + t\frac{dW(u_1)}{du_1} = \frac{dC_2(U_0-u_1)}{du_2} \quad (19)$$

The economic interpretation is the following:

The marginal cost for upgrading at the source minus the marginal reduction of the transport cost, thanks to upgrading at the source, should equal the marginal cost of upgrading at the mill. We can conclude that the marginal costs of upgrading, with consequences such as transport cost changes considered, should be the same in both locations. This can be generalized to the following statement: Within a supply chain, the expected marginal costs of upgrading, with all consequences such as transport cost and industrial value changes considered, should be the same in all locations. In order to show this formally, we would however need considerable space for the text and equations.

Effects of changing conditions

In this section, we will derive some rather strong analytical results of a general nature, based on the two location upgrading optimization problems. Comparative statics analysis will be used. In order to get explicit results, we first have to specify the relationship between the costs of pretreatment, or upgrading, in different locations.

Let us introduce a constant, $y > 0$, and make the following assumption about the relationship between the two upgrading cost functions:

$$C_1(x) = yC_2(x) \quad (20)$$

The maximization problem becomes:

$$\max \pi(u_1) = -yC_2(u_1) - tW(u_1) - C_2(U_0 - u_1) + k \qquad (21)$$

The first order optimum condition is:

$$\frac{d\pi}{du_1} = -y\frac{dC_2(u_1)}{du_1} - t\frac{dW(u_1)}{du_1} + \frac{dC_2(U_0 - u_1)}{du_2} = 0 \qquad (22)$$

Let us make the assumption of a unique maximum. The second order derivative of the objective function with respect to the decision variable is strictly negative:

$$\frac{d^2\pi}{du_1^{\,2}} < 0 \qquad (23)$$

If one of the parameters, t or y, changes, the optimal value of u_1, u_1^*, changes. The exact value of the change of u_1^*, du_1^*, is determined this way:

Differentiation of the first order optimum condition gives:

$$d\left(\frac{d\pi}{du_1}\right) = \left(\frac{d^2\pi}{du_1^{\,2}}\right)du_1^* + \left(\frac{d^2\pi}{du_1dt}\right)dt + \left(\frac{d^2\pi}{du_1dy}\right)dy = 0 \qquad (24)$$

Case 1:

First: Assume that the transport distance remains constant. $dt = 0$. As a consequence:

$$\left(\frac{d^2\pi}{du_1^{\,2}}\right)du_1^* + \left(\frac{d^2\pi}{du_1dy}\right)dy = 0 \qquad (25)$$

This can be rearranged to:

$$\frac{du_1^*}{dy} = \frac{-\left(\frac{d^2\pi}{du_1dy}\right)}{\left(\frac{d^2\pi}{du_1^{\,2}}\right)} \qquad (26)$$

Finally,

$$\frac{du_1^*}{dy} = \frac{\left(\frac{dC_2(u_1)}{du_1}\right)}{\left(\frac{d^2\pi}{du_1^{\,2}}\right)} < 0 \qquad (27)$$

Since $u_2 = U_0 - u_1$, we also know that $u_2^* = U_0 - u_1^*$. As a consequence:

$$\frac{du_2^*}{dy} = -\frac{du_1^*}{dy} \qquad (28)$$

This means that:

$$\frac{du_2^*}{dy} > 0 \qquad (29)$$

So, if the cost of upgrading at the source increases in relation to the cost of upgrading at the mill, the optimal level of upgrading at the source decreases and the level of upgrading at the mill increases. In many cases, upgrading at the source may be more expensive than upgrading at the mill because of economies of scale at the mill. Furthermore, more specialized equipment can be used at the mill and frequent transport of upgrading equipment to different sources is avoided.

On the other hand, some types of time and space intensive upgrading can be more expensive at the mill than at the source, because the required space typically is cheaper to rent and use at the source than at an industrial site close to the mill. The influences of these particular conditions on the optimal upgrading and pretreatment decisions at different locations can be investigated via the derived equations.

Case 2:

Now, let us assume that the relationship between the upgrading, or pretreatment, cost functions in different locations remains constant. $dy = 0$. As a consequence:

$$\left(\frac{d^2\pi}{du_1^{\,2}}\right)du_1^* + \left(\frac{d^2\pi}{du_1dt}\right)dt = 0 \qquad (30)$$

This can be rearranged to:

$$\frac{du_1^*}{dt} = \frac{-\left(\frac{d^2\pi}{du_1dt}\right)}{\left(\frac{d^2\pi}{du_1^{\,2}}\right)} \qquad (31)$$

Finally,

$$\frac{du_1^*}{dt} = \frac{\left(\frac{dW(u_1)}{du_1}\right)}{\left(\frac{d^2\pi}{du_1^{\,2}}\right)} > 0 \qquad (32)$$

Since $u_2 = U_0 - u_1$, we also know that $u_2^* = U_0 - u_1^*$. As a consequence:

$$\frac{du_2^*}{dt} = -\frac{du_1^*}{dt} \qquad (33)$$

Which means that:

$$\frac{du_2^*}{dt} < 0 \qquad (34)$$

So, the optimal level of upgrading at the source is a strictly increasing function of the transport distance. This is reasonable since upgrading at the source makes the transport cost per kilometer lower. This is more important if the transport distance increases.

Forest biomass is a resource that is spatially distributed. Hence, the transport distance gradually increases, as the total volume of forest biomass increases.

As a result, the optimal level of upgrading, or pretreatment, at the source, gradually increases with the transport distance. Furthermore, the optimal level of upgrading, or pretreatment, at the mill, decreases with the transport distance. The influence of transport distance on the optimal upgrading and pretreatment decisions at different locations can be investigated via the derived equations.

Optimal decision combinations and adaptive decisions

In the earlier sections, we considered upgrading and pretreatment as continuous decision variables. This is often a relevant approach when we can gradually adjust the level of upgrading. Sometimes, we are constrained to a more restrictive set of alternatives. Maybe we already have standardized pretreatment and upgrading processes, equipment that can only be used with a limited set of fixed or predefined processes etc. Furthermore, with processes that have significant set up costs, gradual upgrading, in several stages, is sometimes not an economically rational option. Then, you may have to select between upgrading in one location or the other. In such cases, we may have to consider pretreatment and upgrading as discrete decision optimization problems. The analytical tools to be used in such cases include linear and nonlinear programming with constraints, for instance quadratic programming. Sometimes it may be necessary to define the decision variables as binary or integer variables. In some cases, the derivations will lead to corner solutions even without explicit definitions of the decision variables as binary variables or integers.

In many multi period supply chain problems with pretreatment, dynamic programming is a relevant and useful tool. This method can also efficiently handle integers. Stochastic dynamic programming can handle sequentially updated information and decisions that are conditional on such information. This is often very important, since several conditions that influence optimal decisions in the supply chains with pretreatment and upgrading options may change over time in ways that can not be perfectly predicted. Lohmander (2007) describes these methods and contains typical applications from the forest sector.

A stochastic dynamic programming problem formulation, for sequential upgrading and pretreatment optimization, with at least one more period remaining before the planning horizon, is the following:

$$W^*(i,t) = \max_{\substack{h \\ h \in H(i)}} \left(R(i,t,h) + e^{-r} \sum_{j=1}^{J} \tau(j \mid i,t,h) W^*(j,t+1) \right) \qquad (35)$$

t denotes the time period. The state, i, includes all necessary information about the relevant conditions at a particular point in time, such as the amount of available forest biomass and its spatial distribution, the capacity levels of upgrading and pretreatment equipment in different locations, prices of forest biomass with alternative pretreatment levels in different locations etc.. W is the objective function, the expected present value of all revenues minus costs, as a function of the initial state and time period. Stars indicate optimal values. h is the decision (or combination of decisions), including upgrading or pretreatment decisions and pretreatment and upgrading equipment investments, at time t.

h must belong to the feasible set $H(i)$. The feasible set represents the options available for upgrading and pretreatment, investments etc., if the entering state is i. $R(i,t,h)$ is the profit made in period t, as a function of the initial state, the period and the decision(s) in that period. e^{-r} is the one period discounting factor where r

is the rate of interest in the capital market. $\tau(j\,|\,i,t,h)$ represents the transition probability, the probability of entering state j in period $t+1$, if the entering state in period t is i and decision(s) h are taken in that period.
Sometimes, it is necessary to specify the value of W also in the final planning period, at the horizon. Here, in this descriptive context, this will not be done. In general, relevant definitions of objective functions in the respective final periods, are highly application specific.

DISCUSSION

Forest biomass and environmental constraints

The optimal forest biomass pretreatment and upgrading decisions are strongly dependent on infrastructure, forest production conditions and environmental constraints. In some countries, such as Norway, Sweden and Finland, the CTL (Cut To Length) harvesting method is usually applied. With that method, thinnings and clearfellings are mostly performed with harvesters and forwarders. Goltsev et al (2011) describe important properties of several harvesting systems. The harvester cuts the stem into different parts, logs. Branches and tops are removed and left on the ground. The logs are usually denoted timber, pulpwood and energy wood, depending on the intended use of the logs. However, the optimal use of a particular log is a function of prices, location, transport costs etc.. In Sweden, as one example, wood initially defined as pulpwood is often redirected to the energy industry. Timber, pulpwood and energy wood are moved from the sites where the trees have been standing to the closest forest roads by forwarders. Sometimes GROT (Branches and tops) is collected and transported to the forest roads by the same type of machine. Roots, stumps, are sometimes removed from the site and used in the energy industry. Generally, it is expensive to harvest the roots, stumps. Furthermore, GROT is often very difficult, and expensive, to harvest in case the harvest is not a final felling or clear felling. In some countries, such as Switzerland, clear felling is not a method that is accepted in the forest act. In most cases, environmental values are considered to be higher in continuous cover forests, forests that never are completely harvested. In continuous cover forestry, the growing stock is always strictly positive and partial harvesting occurs sequentially. Mostly, the largest trees are harvested each time. The relative frequency distribution of trees with different sizes remains more or less constant over time. Some of the important decision variables in continuous cover forestry are the stock level after thinning and the harvest time interval. A recent study of optimal continuous cover forestry is Lohmander and Mohammadi (2008).
Typical consequences for optimal forest biomass upgrading and pretreatment, of differences in infrastructure, forest production conditions and environmental constraints, are the following: In areas with limited infrastructure in the form of railroads and permanent roads, and long distances between forest roads, the costs of collecting and transporting GROT, branches and tops, are large. As a result, it may be unprofitable to collect such forest biomass and optimal pretreatment and upgrading activities approach zero. That is the case in the short run. In the long run, investments in infrastructure and forest management decisions should be optimized in combination. In countries where clear fellings (sometimes denoted final fellings or clearcuts) are not legally accepted, continuous cover forestry is the only alternative. Then, we should not expect it to be economically rational to collect GROT, branches and tops, using the CTL method with harvesters and forwarders. One interesting alternative, in order to get access to forest biomass from branches and tops, in that situation, is to use the “full tree method”, with feller - bunchers and skidders. With that system, we can move complete trees from the original positions in the stands to the nearest forest roads, where all of the different assortments, timber, pulpwood, energy wood, branches and tops, will be made available for transport. It is likely that it is more rational to transport most trees, in the upright position, from the positions in the stands to the forest roads, with the feller – buncher, than to let the trees fall and pick them up with skidders. If trees fall in the continuous cover stands,

and are dragged to forest roads by skidders, it is likely that considerable damages of plants and other trees occur. Such damages may imply considerable costs in later periods. So, in case continuous cover forestry is combined with CTL methods, pretreatment and upgrading of branches and tops will usually not be rational options. On the other hand, if feller-bunchers are available and used in such forests, pretreatment and upgrading of tops and branches can be expected to be rational decisions. The optimal levels of such activitites can however not be determined without explicit optimization.

Future applications, relevance and developments

Pretreatment and upgrading of forest biomass are important activities in the supply chains of forest biomass and other forest products, such as timber and pulpwood. In order to obtain the best possible total solution, with the highest obtainable total profitability, it is necessary to optimize all activitites in the supply chains with the relevant links and dependencies under consideration, spatially, and over time. This chapter is a briefing on central methods, principles and general results within this area. Now is the time to consider future developments in this field. The author suggests that concrete forest biomass supply chains are inspected in the light of the ideas found in this chapter. With locally relevant empirical background, the general mathematical models and results can be transformed to locally relevant numerical optimization models. With such models, the locally relevant optimal pretreatment methods and upgrading levels will be found. A special challenge is to formulate the locally relevant problems as stochastic dynamic programming problems. This is however a very important area of development, since the future state of the world is indeed not certain. Risk and transition probabilities have to be considered when we optimize our pretreatment and upgrading decisions in the forest biomass supply chains of the future.

It is important to be aware of the fact that the model is constructed in order to optimize the total result. This may, by some readers, be regarded as a restriction or shortcoming, in the light of the structure of the real world. A pessimistic view on how the world functions is to say that each firm tries to maximize the profit of that particular firm, not the complete system with many firms or the complete supply chains. A more optimistic view is to say that firms can and should cooperate to find solutions that improve the total result of the complete system. The distribution of this total result is another topic. Furthermore, one may argue that if the market economic system as a whole functions well, then the total economic surplus is maximized, even if individual firms just act in their own interests. Finally, within centrally planned economies, optimization of the total result is clearly relevant. Irrespective of how we view the properties of the world, we should always be interested to obtain the best obtainable total result.

The author suggests that a numerically specified version of model is developed that includes the forest regions of Norway, Sweden, Finland, Russian Federation and the Baltic states, and the highly populated and industrialized regions of Europe and East Asia. A similar model should be developed for North America, including the forest regions of Canada and the more strongly populated areas of USA, in particular the coastal regions of the Pacific and Atlantic oceans. Of course, the other continents should also be analyzed in the same way and a complete version of the model should finally be developed to handle the global level.

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استدلال و پیش تدارک بیوماس جنگل

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چکیده

در مناطق بزرگی از دنیا، زیتوده (بیوماس) یک منبع مهمی از انرژی می باشد. بازار انرژی زیستی در دنیا بر اساس بیوماس جنگلی به سرعت در حال رشد است. در حدود ۹۲٪ از انرژی زیستی در سوئد از جنگل ها حاصل می شود. بیوماس جنگل ها مشابه نیست. موقعیت ها، فواصل حمل و نقل و شیوه های انتقال می تواند خیلی متفاوت باشد و صنایعی که به بیوماس بعنوان یک انرژی احتیاج دارند مواد خام با خصوصیت های متفاوت را ترجیح می دهند. بطور کلی، از لحاظ اقتصادی بیوماس مطلوب جنگل و روشهای عملیاتی پیشین می بایستی با در نظر گرفتن کارکرد عینی وابسته، محدودیت ها و ساختار اطلاعاتی تخمین زده شود. آرمانها و اهداف این مقاله بررسی موارد خاص و استخراج قوانین کلی برای ترکیبات بهینه بیوماس جنگل و همچنین روشهای عملیاتی در مواقع ضروری است. مدلهای ریاضی تعریف شده اند که بیانگر نسخه های مختلفی از آمایش بیوماس جنگل، به روز رسانی و پیش تدارکات مشکلات بهینه سازی می باشد. قواعد کلی تصمیم گیری های بهینه بر اساس این مدل ها مشتق می شود و پیشنهادات برای تحقیقات آتی و برنامه های کاربردی ارائه می شود.