International Institute for
Applied Systems Analysis
Schlossplatz 1
A-2361 Laxenburg, Austria

Tel: +43 2236 807 342
Fax: +43 2236 71313
E-mail: publications@iiasa.ac.at
Web: www.iiasa.ac.at

Interim Report **IR-08-043**

Profitability of Short Rotation Forestry in Austria

Martin Schönhart (schoenhart@gmx.at)

Approved by

Anatoly Shvidenko
Acting Leader, Forestry Program

7 November 2008

Contents

Abstract

This study focuses on the economics of short rotation forestry (SRF) in Austria and is based on a net-present-value calculation. The aims of this study were to evaluate the profitability of SRF under various scenarios and to provide information on economically optimal production decisions. Dynamic systems analysis was applied to model biophysical growth, costs, and benefits of a poplar plantation. The model includes two different harvesting systems (cut-and-chip harvester, feller-buncher harvester) and two transportation systems (transportation of wood chips with tractor or truck). The model takes into account variations in biomass growth based on different plant densities and rotation periods as well as biomass decay and heating value depending on the chosen harvesting system and length of storage. The results indicate that SRF can be profitable under certain conditions in Austria.

Acknowledgments

This study was conducted during IIASA's Young Scientists Summer Program (YSSP) in 2006 under the supervision of Michael Obersteiner in the Forestry Program. His assistance throughout the whole research process and beyond is gratefully acknowledged. I am also grateful to Felicjan Rydzak for his help and patience during the modeling process. Furthermore, I would like to thank the staff of the Forestry Program and my YSSP colleagues for the helpful, stimulating and challenging environment they provided during the summer.

About the Author

Martin Schönhart is a student of agricultural economics at the University of Natural Resources and Applied Life Sciences in Vienna and of political sciences at the University of Vienna.

Profitabilitty of Short Rotation Forestry in Austria

Martin Schönhart

1 Introduction

1.1 The Oil Crisis and Beyond

The oil crisis during the early 1980s gave rise to an intense search for alternative energy sources. One of the investigated options for replacing fossil fuels was biomass produced on agricultural land. Rapidly growing tree species with high annual biomass increments came into the spotlight of agricultural policy, and agricultural research followed accordingly. Several field experiments were established in Austria at that time (for an example, see Pelzmann, 1992). Nevertheless, the situation changed again. With decreasing oil prices and supposedly secure future supply of fossil fuels, public interest in alternative energy sources decreased again. The currently high prices for fossil fuels, concerns about negative consequences of human induced climate change caused by the emission of greenhouse gases (GHGs), and political considerations related to the stability of raw material supply brought biomass *back on stage*.

Agriculture offers several possibilities to supply energy. Among energy plants, short rotation forestry (SRF) is one production concept. It relies on pioneer trees with high basic biomass growth rates and the ability to resprout after harvest (Kauter *et al.*, 2003). The most prominent and relevant species for Central Europe are Populus sp. and Salix sp. with yields of 8 to 12 t DM per hectare (ha) and year (Makeschin, 1999). Production is based on rotation periods of up to 30 years, but stricter definitions on SRF conceive 10 to 12 years as the maximum period (Weih, 2004). In general, the plantation lifespan is between 20 to 30 years.

Research on biomass plantations on agricultural land must also take into account economic considerations from the point of view of farmers. This information not only proves the feasibility of policy targets, but can also reveal influential factors of production as an aim for further research. For Austria, only a few cost calculations on SRF are published (see for example, Traupmann, 2004 or Heiss, 2006). They are often based on static investment calculations like the contribution margin. Such calculations are not appropriate for SRF if they do not take into account the long lifespan of plantations, the high amount of investments necessary for site establishment, and the production and market risks. Furthermore, the high share of specialized machinery, which is often not available on farms, makes simple calculations on the contribution margin less meaningful.

1.2 Aims of the Study

The aim of this study is to investigate the profitability of SRF in Austria from the point of view of agricultural entrepreneurs. In general, production conditions and methods for SRF vary significantly. Variations, among others, are related to the used species, the available machinery, and the final product. Any calculation on SRF projects must take these disparities into account in order to allow meaningful statements on profitability. Therefore, sensitivity analysis is applied in this study, which also reveals the most influential input parameters, shows issues for further research, and the potential of technical improvements.

A further aim is to provide information on optimal production decisions based on defined input parameters. Many production decisions of SRF are interrelated to each other, which makes optimization of production methods difficult. Important, among others, is the relationship of rotation period and plant density, which is also of central importance to this investigation. Economic studies often do not address these interrelations and, for example, assume a plant density and a rotation period (see for example, Rosenqvist and Dawson, 2005; and Toivonen and Tahvanainen, 1998).

2 Short Rotation Forestry—Review of Production Methods

Experiments revealed that SRF is possible on most arable land all over Austria with respect to climate conditions (Raschka, 1997). Nevertheless, restrictions from an agronomic perspective are possible through unfavorable soil conditions (permanent wet soils, unfavorable pH, high stone contents), dry locations with precipitation < 600 millimeters (mm) and sites with low average temperatures (SAC, 2000; Mitchell *et al*., 1999). From an economic point of view, decisive among others are yields, production costs and opportunity costs of land and labor.

Production actually starts with the choice of an appropriate site and a well-suited clone. Using different clones for one plantation reduces the risk of yield losses (Makeschin, 1999). Planting thereby should be done in blocks of the same clones to reduce competition between them. It is widely accepted that proper site preparation is necessary for a successful site establishment (see for example Kauter *et al*., 2003 and Friedrich, 1999). Plants should be able to root deeply and competition from other species for sunlight and water should be minimized during the juvenile development stages (Kauter *et al*., 2003). A herbicide application in fall prior to planting in spring seems not to be appropriate (Friedrich, 1999), although experts disagree on this issue. Mitchell *et al*., (1999), for example, suggest this method for willow planting in Great Britain. The common planting material consists of cuttings with a length of about 20 centimeters (cm) and a diameter of 1 cm. They are often planted with specialized machinery. The planting process must guarantee proper soil compaction around the young plant and an appropriate planting depth (Friedrich, 1999). Planting of rods proved also to be successful (Hofmann, 2005), but might only be relevant for low plant densities. Controlling is especially important for modified agricultural planting machinery because they do not provide the same process quality as dedicated planting machines for cuttings (Friedrich, 1999). A further possibility for site establishment would be manual planting. In literature, a threshold of 2 ha is stated for a shift from manual to automatic planting systems (Friedrich, 1999). From an economic point of view, such a statement must be proven with respect to the share of fixed and variable costs of planting, labor costs, and the difference in productivity of mechanical and manual planting. In terms of quality, no differences between manual and mechanical planting has been observed (Friedrich, 1999; Hofmann, 2005). Density depends on the species used, the product end use, the length of the rotation period, and finally on economic considerations. Site establishment must already take the likely harvesting method into account. For the Claas Jaguar, twin rows with a distance of 0.75 meters (m) between the two rows and about 1.5 m between the twin rows are recommended in order to guarantee optimal harvesting conditions (Weigelt, 2006). For mechanical maintenance with common agricultural equipment, the distance between twin rows must possibly be even larger.

Plant density influences yields depending on the rotation period. The higher the density on a site, the shorter the period until the maximum mean annual biomass increment (MABI) is reached. Although it maximizes biomass production, this point does not automatically determine the economically efficient rotation period over a long period of time with constant land use (Mead, 2005). With longer rotation periods, competition in dense stands reduces growth vigor (Kauter *et al*., 2003). Additional yield effects of very high densities likely occur only during the first few rotations and depend on the yield potential of the clone (Friedrich, 1999). Later, an equilibrium density of between 0.6 to 0.9 m within a row might be reached. Frequency of harvest influences yields too. According to Meads (2005), yields reach their maximum in the second rotation and productivity decreases afterwards, caused by reduced stool vigor or dead plants. This supposition is in contradiction to the findings of Kopp *et al*. (2001), who annually harvested willows over a 10-year period and revealed consistent productivity. Furthermore, a review of experiments proved yields in the first rotation period to be higher than in the second one for more than 50% of all investigated cases (Mitchell *et al*., 1999). Planting density also influences diameter growth of single plants, which determines the time until which cheap cut-and-chip harvesters can be used. Site establishment costs can heavily depend on costs for planting material and therefore on spacing.

After planting and prior to sprouting, the application of herbicides is often recommended in order to reduce weed pressure during the first critical weeks of plants growth. Depending on site conditions and predetermined by previous land use, this measure could be enough for the whole growing season, but high variations are possible. Coppicing after the first year is not recommended for poplar after experiments did not reveal any yield increasing effects (Herve and Ceulemans, 1996). For Friedrich (1999) coppicing is justifiable economically only if cuttings are used as planting material. Cuttings of the previous year for site establishment of a new SRF plantation can be competitive depending on the productivity and costs of preparing the planting material, the market prices for cuttings, and the differences in quality between both. Heaton *et al*., (1999) in their economic analysis suggest a system with annual planting during the first rotation period on one site. It offers the advantage that farmers, after the first rotation period, can obtain an annual income from their SRF plantations, but at the expense of economies of scale. Furthermore, such a system can increase environmental quality as it permanently provides habitat for wildlife and might reduce habitat fragmentation.

Susceptibility for diseases as well as wildlife in general depends on clones. Preventive mechanical plant protection can be necessary in regions with high populations of harmful wildlife, which are especially deer and rabbits. Replacement plantings can be appropriate in the year after site establishment if losses of plants are high. However, Friedrich (1999) reports only partial success of this measure for their planting experiments in Germany. Beside damage through wildlife, insects and diseases can harm the plantation severely. The most important among diseases is Melampsora rust (Makeschin, 1999).

Periodical harvest in short intervals is one of the special properties of SRF. A great variety of harvesting systems exists. Every system can be separated into four main operations, which are cutting, collection, extraction, and comminution (Spinelli and Kofman, 1996). Mechanization goes from manual harvest to cut-and-chip harvesters, which produce wood chips in one single step. After harvest, wood can be stored or directly used as fuel wood in biomass power plants, for alcohol production, or for production of chemicals.

Environmental effects of SRF plantations are still unclear and depend on site and management specific conditions. The EEA (2006) regards risks of pressure on environment as low for erosion, soil compaction, nutrients inputs into water, and pesticide pollution. According to this study, water extraction and landscape are partial risks. A detailed assessment for Sweden was done by Börjesson (1999). He concludes that environmental benefits can be substantial based on the assumption that intensively used agricultural land is replaced by perennial crops. If SRF is not established on fertile arable land but on land at the margin, environmental effects might decline or even become negative. Trinkaus (1998) supposes some locations in Austria to be at risk and gives design principles for nature conservation and environmental protection. Effects of SRF on biodiversity depend on the structure of the regional farm land. In an intensively used agricultural landscape with a high share of large fields, it might lead to environmental improvements, especially if it links formerly separated ecosystems to each other (Trinkaus, 1998). SRF plantations are regarded as a low input crop with a favorable energy balance. Biomass from willows, for example, produces 55 units of energy from one unit of fossil fuel energy input (Heller *et al*., 2003). Effects on the carbon balance of a site are a further environmental property. SRF not only influences the above ground biomass pools, but also has effects on soil carbon. Besides, replacements of CO_2 emissions from fossil fuels through those from biomass are possible. For a plantation lifespan of 25 years, carbon benefits of 125.5 t C/ha for biomass yields of 13 t DM/ha and year, and 97 t for 10 t had been estimated (Schönhart, 2006).

3 Methods and Data

3.1 Basics about the Model

A model was built in VENSIM®, which is a specialized software tool for dynamic systems analysis. The special feature of system dynamics is the focus on feedback loops in complex systems. Stocks and flows are designed in order to connect these feedback loops and allow their expression (MIT System Dynamics Group, 2006). The model is based on biophysical and monetary flows and stocks. Monetary costs and benefits thereby are coflows of the biophysical model part. A feedback loop is, for example, the reduction of biomass growth caused by harvest.

The economic assessment is based on a net-present-value (NPV) calculation. This approach takes into account the long lifespan of SRF plantations and the long interval between inflows and outflows of capital.

$$NPV = \sum_{t=0}^{T} \frac{(B_t - C_t)}{(1+i)^t} \tag{1}$$

Equation (1) presents the *NPV* as the discounted sum (*i* = discount rate*)* of all market benefits (*B*) minus market costs (*C*) of a specific year. A project is considered to be economically viable if its $NPV \geq 0$, which signifies that the discounted costs are smaller than the discounted benefits. Of crucial importance to investment calculations is the question, which costs are considered in detail. For decisions in agriculture, the contribution margin is commonly used. It is derived from the revenues of a project reduced by variable costs and gives the contribution of the project to the repayment of the fixed costs of the enterprise. Full resource cost accounting on the other side considers all costs of a project. It also takes into account calculative costs for capital and taxes. While the first one is easy to apply but does not allow statements on the absolute profitability of a project, the second one is difficult to calculate and does not necessarily suggest optimal decisions in cases were investments, for example in machinery, have already been made (Perlack *et al*., 1996). The calculation in the model takes into account costs for materials, e.g., for cuttings and fertilizer, and labor costs. Machinery costs are calculated based on both fixed and variable costs. Opportunity costs for the land are considered via a rate for renting land. No additional capital costs have been calculated with the exception of costs for machinery (interest rate for machinery investment as part of fixed costs). Initial investment is considered through discounting and investments beyond that point are assumed to be paid directly with the earnings from the project. The value-added tax is included in all rates. The project is assumed not to change the income of the farm considerably and hence does not influence the farms *lump sum* tax rate. Data for costs on machinery is taken from ÖKL (2006) or from literature in cases were country specific values were missing. Information on production methods is based on literature and expert views.

3.2 Biophysical Stocks and Flows

The model for biomass production is shown in Figure 1. Biomass accumulation is based on a biomass growth rate. No difference in growth rates has been made between the first and subsequent rotation periods if not indicated otherwise. In order to take into account the influence of spacing and rotation period on MABI, biomass growth multiplication factors were derived from a long-term study on poplars in the US (Strong and Hansen, 1993). Figure 2 shows the MABI for different plant densities and rotation periods. Data had to be transformed to meet the needs of the model. These changes are indicated by the doted lines in the graph (for a detailed description, see Appendix 1).

The multiplication factors are based on the MABI of a plantation with 10,000 plants/ha and a rotation period of six years. The biomass growth rate in the model is obtained by multiplying these factors by an assumed basic yield for the same density and rotation period. This yield expresses the yield potential of the site. The distances between the plants used in the graph to describe the planting density are derived from the cited study, but do not indicate the actual planting structure. This structure relies on the needs of the harvesting and maintenance system. Nevertheless, plant densities per ha are kept constant. They are 27,778 plants for spacing 0.6 m × 0.6 m, 10,000 for 1.0 × 1.0, 6,944 for 1.2 × 1.2, 3,086 for 1.8 × 1.8 and 1,736 for 2.4 × 2.4. Other densities are not simulated with the model.

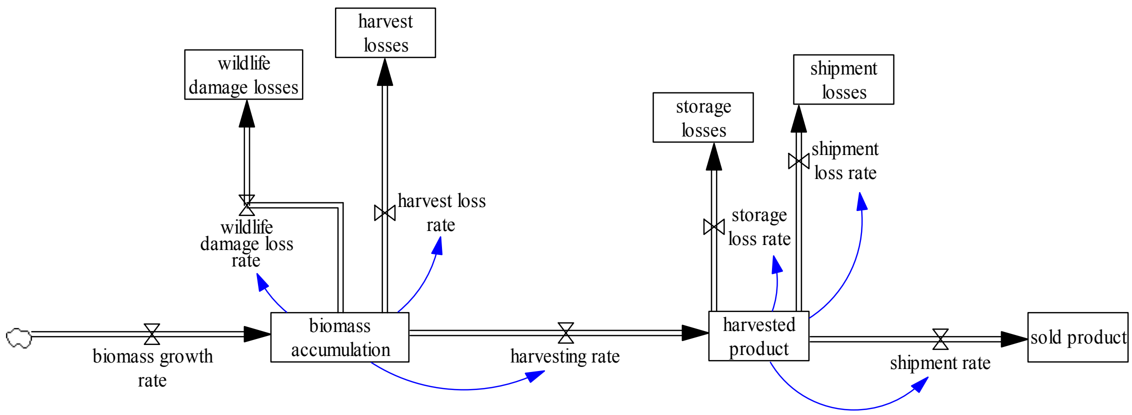


Figure 1: Biophysical stocks and flows of a poplar plantation. Source: Author's construction.

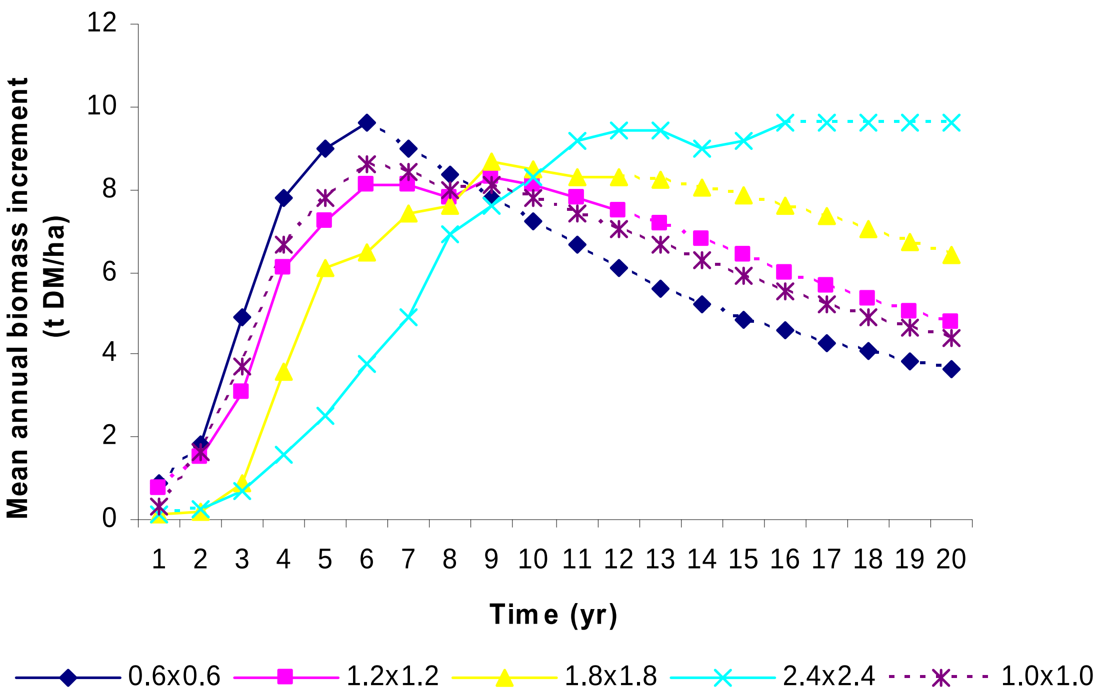


Figure 2: Mean annual biomass increment of a poplar plantation in t DM/ha with different spacing in m. Source: Author's construction based on Strong and Hansen (1993).

Damage by wildlife reduces harvestable biomass stocks as an assumed percentage of biomass accumulation. Losses can be prevented by the establishment of a fence. The site is harvested periodically after a defined rotation period. Harvest clears the biomass stock and builds the stock of harvested products. Two harvesting systems are available in the model. A cut-and-chip system (felling and chipping in one step) is carried out by a Claas Jaguar with a dedicated SRF header. The second harvesting system consists of a feller-buncher header on a forestry harvester, which cuts trees with a blade and bundles stems. Bundles are picked up later by a front-end loader and are chipped on the site immediately prior to shipping by a stationary truck-mounted chipper. Harvest losses are taken into account as a share of the harvestable biomass stock and depend on the chosen harvesting system. For the cut-and-chip system, Hartmann and Thuneke (1997) report average losses of 4.6%. For the feller-buncher harvesting system, no values are available. 1% is assumed here as input value because a more precise harvest can be expected. In contrast to the cut-and-chip harvester, the feller-buncher harvester has a blade instead of a disc saw for cutting. Concerns about stock damage caused by this cutting process of the feller-buncher harvester have not been confirmed by experts (see for example, Burger, 2006). The stock of harvested products can be reduced by storage and shipment losses. Storage losses depend on the kind of stored product. Wood chips likely have larger biomass decay rates than whole stems and lose up to 3% of biomass per month (Mitchell *et al*., 1999; Scholz *et al*., 2005) depending on various conditions like, for example, pile height or particle size (Jirjis, 2005). In the model, biomass decay of wood chips begins 1.2 month after harvest assuming that lower temperatures in winter reduce biomass decomposition. Biomass decay of whole stems is lower (Mitchell *et al*., 1999), but likely still exists. Storage of whole stems is assumed to reduce biomass by 0.5% per month. Shipment again causes biomass losses of 2%. Wood chips are stored on the site, which makes loading operations more difficult and higher losses justifiable. Wood chips are frequently stored on tarred sites in reality, which would reduce loading losses, soil compaction, and perhaps even loading time. On the other side, such a storage system is more resource demanding during harvest because of longer transportation distances.

3.3 Costs of Production

Production costs strongly depend on the scenario and, hence, detailed definitions of underlying production methods are necessary. Unless indicated otherwise, the measures below are applied. A detailed description on input parameters for the calculation is presented in Appendix 2.

Site establishment costs consist of soil preparation, planting, management, and plant protection costs. Here, plowing and harrowing is done in spring directly prior to planting. For Austria, specialized planting machinery is not available and hence a modified agricultural planting machine is used. For planting, three persons on the machine and an additional one for controlling are necessary. Chemical plant protection is not applied. Instead of that, mechanical weed control is undertaken three times during the year of establishment and includes manual weed control of about five hours per ha. A fence protects against wildlife damage. Most of the establishment costs can be used to calculate costs for more than one ha. For management and fence construction this is not true. The market for planting materials is not highly developed in Austria, which leads to relatively high prices in the high quality segment. Poplar cuttings can be imported from Italy for 0.18 € per piece and willow cuttings from Sweden have been imported for 0.085 € (Mayer, 2006).

After establishment, costs occur for maintenance of the site, harvest, shipping of the product, land, and finally for recultivation. Controlling the planting process is included and, hence, a high establishment success can be assumed, which does not justify replacement plantings in the year after establishment. Maintenance consists of management with five h/ha and year and weed control in each year after harvest. For densities of less than 3,087 plants/ha, weed control is also applied in the second year because weed suppression through canopy closure begins later. Fertilizer application is necessary in order to avoid nutrient depletion of the soil. It is done after each harvest based on data for the extraction of nutrients during a four-year rotation period under various yield scenarios (see Appendix 3 for details). Liming and application of magnesium is assumed not to be necessary. In order to avoid negative effects on the environment, fertilizer amounts are restricted by an upper threshold of 200 kg N/ha, 200 kg P and 250 kg of K. Amounts per application are limited too, but costs are assumed to stay the same independently from the number of applications per year. These thresholds are more important for longer rotation periods with higher fertilizer application rates and therefore might understate fertilizer costs. On the other side, longer rotation periods reduce the relative content of bark, which contains most of the nutrients (Tharakan *et al*., 2003). This second effect likely decreases nutrients extraction and hence might reduce wrong estimates caused by the first effect.

Harvesting systems have already been described before. The Claas harvester is of special interest, as it is already used in agriculture in Austria. A further use for harvest of SRF plantations in winter would likely decrease costs. Net productivity on site n ($NP_{Claas,\ n}$) in t FM/h is estimated with equation (2) based on the site specific fresh matter yield in t/ha ($Y_{FM,n}$). Data for the regression ($R = 0.71$) is taken from various experiments (for details, see Appendix 4).

$$NP_{Claas,n} = 0.5767 * Y_{FM,n} + 7.6052 \tag{2}$$

Harvest interruptions and time for trailer and row change reduce NP_{Claas} and lead to the gross harvest productivity (GP_{Claas}). The machinery is accompanied by a tractor-trailer unit for chips transportation. Chips are stored in piles on the headlands of the field. The parallel system, used in the model, is justified by the high costs of the cut-and-chip harvester per hour in comparison to costs for tractors and trailers and by the lack of knowledge on field shapes. Alternatives would be trailers, which are directly attached to the harvesting machinery. However, these systems reduce the power available for harvesting and might also considerably increase GP_{Claas} if the length of the site does not fit with the trailer capacity pulled by the harvesting machine. The influence of this important effect on harvesting costs per unit is shown by Hartmann and Thuneke (1997). The net productivity of the feller-buncher harvester on site n ($NP_{fell\text{-}bunch,\ n}$) in t FM/h is presented in equation (3) ($R = 0.49$; for details, see Appendix 5). The input parameter is the weight of stem(s) in kg ($m_{stem(s)}$), which is cut per step. This relationship is suggested by Spinelli *et al*., (2006a). In order to prevent negative values, weights below 1.5 kg were set equal to 1.5 kg.

$$NP_{fell-bunch,n} = -2.1406 + 5.3397 * (\ln m_{stem(s),n}) \tag{3}$$

While bundling of up to eight stems has been reported (Burger, 2006), it is not clear yet if simultaneous cutting of more than one stem is possible. In the model, one stool has two sprouts on average. The use of harvest machinery is determined not only by costs, but also by the diameter of stems. Claas Jaguar can handle diameters of up to 7 cm (Claas Deutschland, 2006), while feller-buncher headers can cut trees up to 20 cm (Burger and Scholz, 2004). In the model the cheapest harvesting system is chosen based on the precondition that diameter restrictions are not limiting. The diameter does not only depend on the rotation period, but also on the plant density and the site-specific growth potential. Equation (4) gives the DM yield/ha (Y_{max}) at which a diameter of 7 cm is reached ($R = 0.98$). It depends on the plant density (d_n) on site n in plants/ha (see Appendix 6 for details).

$$Y_{\max} = 34.537 * \ln(d_n) - 233.87 \tag{4}$$

Wood chips or stems are stored on the headlands. Although this system might increase storage and shipment losses, it reduces harvest costs. According to Senelwa and Sims (1999), storage reduces the water content of wood and therefore enhances wood quality through an increased initial gross calorific value, higher energy efficiency through lower evaporation, and a lower hydrolysis effect. The authors present a function for estimating the higher heating value (HV_{wood}) of *Pinus radiata* in MJ/kg DM depending on the moisture content of the wood in percent of FM (mc_{wood}). This function is used in the model as the effect of moisture on the heating value seems to be independent from species (Senelwa and Sims, 1999).

$$HV_{wood} = -0.1335 * mc_{wood} + 20.15 \tag{5}$$

Drying of whole stems is based on drying factors (see, Appendix 7, for details). For wood chips, drying effects are not clear and therefore are not considered. After several months, slight increases or decreases in water contents of wood chips depending, for example, on pile heights, have been observed (Jirjis, 2005). Drying is assumed to influence the wood chips price. The initial price is paid for a certain amount of energy and a further price is calculated, which keeps the price per unit of energy constant. The overall volume of wood chips is assumed to stay constant during storage, but the weight/m^3 decreases through biomass decay. This effect reduces shipment costs for transportation via trucks because loading capacity of trucks is restricted by weight.

The product is shipped either by tractor or truck. Loading in both cases is done with a tractor mounted front-end loader. The time for tractor-based transportation is estimated with an assumed average velocity. For transportation by truck, equation (6) is used ($R = 0.97$, see Appendix 8 for details).

$$T_{Trans} = 0.084 * d^{0.6718} \tag{6}$$

The time in h needed for one distance to the plant is a function of the distance in km. Transportation capacity depends on both the volume of the trailers and the maximum weight they are allowed to carry. If the tractor-based system is used, loading is done by the tractor driver and additional labor costs do not occur.

Land costs are difficult to estimate as they depend on the specific circumstances of the enterprise. In the basic scenario, they are assumed to be zero because SRF plantations in the model are established on set-aside land, which can hardly be used for other purposes. Alternative non-food products exist, but are not taken into account. In any other case, SRF competes with other land uses, which can be planting of cash crops or lending the land. Opportunity costs for land would then be above zero and would have to be taken into account. One ha of SRF needs more than one ha of land because of the necessary headlands. Their size is based on the relationship of length to breadth of the site. With a length-breath relationship of 1:2, 1.07 ha are needed for a one ha plantation. The breadth of each of the two headlands in this case is five m as is suggested by Makeschin (1999).

The land is recultivated at the end of the plantation lifespan. Costs depend on future land use. In the model, land is prepared again for normal arable use, which is more cost intensive.

3.4 Benefits of Production

Benefits are based on product revenues and subsidies. The basic price in the model is 70 €/t DM. Prices for wood chips in Lower Austria are currently between 66 and 87 €/t DM (Niederösterreichischer Waldverband, 2006). The EU energy crop premium can generally be obtained for SRF plantations. It is currently at 45 €/ha, but cannot be claimed for production on set-aside land. Other subsidies are not included as well. Direct payments are not decisive, as they are decoupled from production and would be available to the farmer at any rate, as long as he fulfills the requirements.

Beside these monetary benefits, calculative benefits can be of interest to the producer. The calculated costs for labor and machinery can be earned by the owner of the SRF plantation if he does some of the work himself. Harvest of SRF plantations occurs in winter during a generally labor extensive time for crop farmers. If machinery from the plantation owner is used, the additional income after subtracting the variable costs contributes to cover the fixed costs. Even if assumed to be a benefit, the full amount of calculative labor and machinery costs cannot be regarded as a benefit because opportunity costs (e.g., leisure time) still exist. Set-aside land must be covered with vegetation and maintained several times a year. These cost savings resulting from the establishment of SRF plantations are not included into the model because they are assumed to be of minor importance.

4 Results

4.1 Basic and Optimal Scenarios

The NPV for the *Basic scenario* after 26 years is –3,068 €/ha. This result is based on a conservative scenario with a discount rate of 4%, a rotation period of five years and a density of 10,000 plants/ha. The main reasons for the negative outcome are high site establishment costs of 3,303 €/ha, harvesting costs of 32.36 €/t DM and shipment costs of 17 €/t DM. Harvest in this scenario is done with the cut-and-chip-system, which is by far cheaper than harvest with a feller-buncher harvester (71.4 €/t DM). Harvest costs in both cases include transportation costs to the headland where the wood is stored. A fence is established. Wood chips with an amount of 213 t DM/ha are sold for a price of 70 €/t DM.

Plant density and rotation period are important and have to be considered prior to planting due to their interrelations. *Basic scenario* was the starting point for optimizing the NPV under varying planting densities and rotation periods via simulation with 120 runs based on a basic yield of 10 t DM/ha. The results are presented in Figure 3.

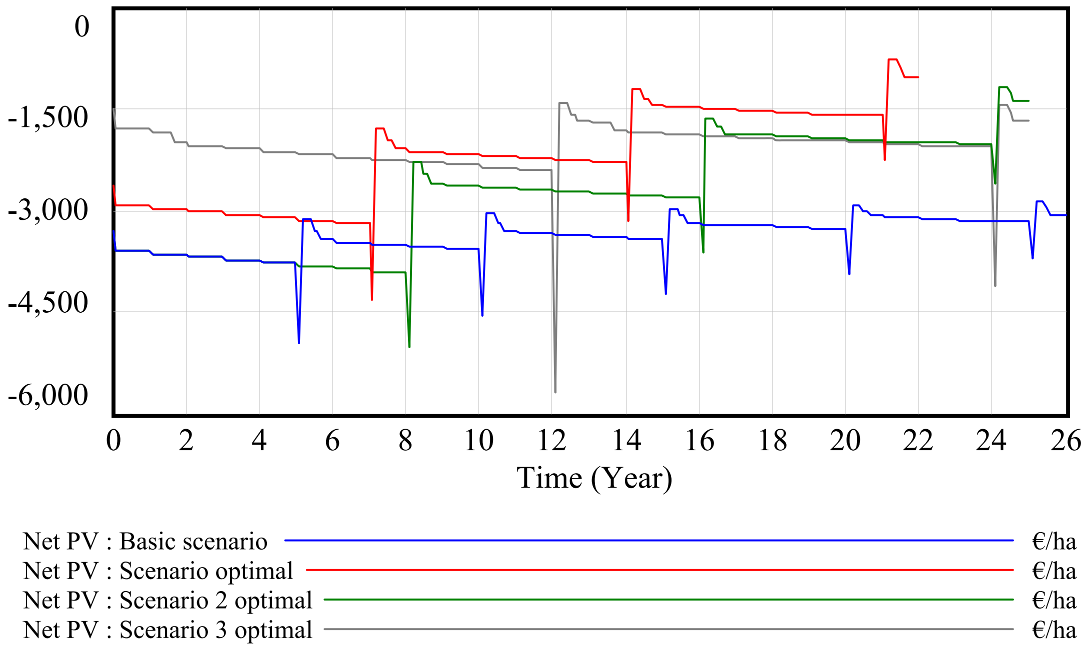


Figure 3: NPV for global and local optima. Source: Author's construction.

Scenario optimal is obtained with a rotation period of seven years and 6,944 plants/ha. The NPV of –1,034 €/ha is reached with a lifespan of only 22 years in comparison to the other scenarios with 25 and 26 years, respectively. This is an additional advantage to the already highest NPV. If the rotation period for this scenario would be extended to 29 years with four rotations, the NPV would increase to –647 €/ha. *Scenario 2 optimal* is based on a rotation period of eight years and a density of 10,000 plants/ha. Its NPV is at –1,392 €/ha after 26 years. Close to this result is *Scenario 3 optimal*. 1,736 plants/ha grow over a rotation period of 12 years and lead to a NPV of –1,682 €/ha after 25 years. The feller-buncher harvesting system is used in this scenario. The lower harvesting costs of *Scenario 2 optimal* can offset the higher establishment costs and the lower growth rates in comparison to *Scenario 3 optimal*. Because of their similar project lifespan and the differences in the applied harvesting system, these two scenarios are used for further analysis. A further similar scenario with respect to the NPV is based on a rotation period of 24 years and a planting density of 1,736 plants/ha. Its NPV is at –1,456 €/ha. Although interesting, this scenario can hardly be considered as SRF and therefore is not discussed in more detail. Rotation periods like this might be too long for farmers to be of interest as the period between investment and returns is too long. NPV for plant densities of 27,778 and 3,086 are too low to be considered here.

Wood in *Scenario 2 optimal* is harvested with the cut-and-chip harvester for 20.7 €/t DM. The maximum diameter with a density of 10,000 plants/ha is reached with a yield of 84.2 t DM/ha. *Scenario 2 optimal* with a rotation period of nine years has a biomass stock only marginally above this threshold at time of harvest (84.6 t DM/ha) and must be harvested with the feller-buncher system. Strong restrictions like this in a model lead to sharp discontinuities. From one year to another, an increasingly cheaper system (increasing productivity of harvesting system through higher biomass stands) is replaced by the model. Sterman (2000, 547) warns of this and states that *"…individual decisions are rarely entirely either/or"*. A similar restriction is the necessary choice of the final time in the model. An extended plantation lifespan in most cases will increase the NPV. In reality, advances in breeding and decreasing yields ease the decision on the maximum lifespan by bringing further criteria into the decision system, which restrict the lifespan economically. A multi-period optimization model would be necessary to solve the problem of the economically efficient lifespan. Here, it is assumed according to literature values instead. To prove the influence of the maximum diameter restriction on the NPV, the maximum rotation period for harvest with the cut-and-chip harvester was extended to nine years. Additionally, the final time was extended to 28 years in order to allow one further harvest. The NPV thereby reached –815 €/ha.

4.2 Production Costs

Presented NPVs until now are negative. Nevertheless, SRF plantations can still be profitable to farmers as the model results must be discussed together with its assumptions. They are conservative, which seems appropriate for a new land use strategy in development and have a considerable reduction potential (see, Rosenqvist and Dawson, 2005 for a discussion).

Figure 4 shows the nominal production costs per application for *Scenarios 2 and 3 optimal*. The most important factors are planting, harvesting, and shipment costs. Effective costs, based on a discount rate of 4%, are presented in Figure 5. The overall importance of costs does not change but harvest of the feller-buncher system becomes relatively cheaper in comparison to the cut-and-chip harvester. This effect is caused by less frequent harvest.

The two scenarios mainly differ in the costs for planting and harvest. A closer look on the planting costs reveals the importance of the expenses for planting material (Figure 6). The higher the price for cuttings and the planting density, the higher is its share on the overall costs of the plantation. It comes to 3% in *Scenario 3 optimal* and 19% in *Scenario 2 optimal*. Increasing prices for cuttings make longer rotation periods with more expensive harvesting solutions relatively more profitable in comparison to rotation periods with high plant densities and lower harvesting costs.

A fence protects from damage from wildlife and its costs should be compared to the prevented losses. For *Scenario 2 optimal*, fence costs are justified with an annual biomass loss of about 6% of the biomass stock.

Beside site establishment, harvesting costs are the second large contributor to the overall costs of SRF plantations. The harvest productivity for both systems depends on the biomass stock of the site as is shown in Figure 7. Higher stocks allow a more efficient harvest. For the cut-and-chip harvester, this effect is independent from the plant density, but only true until the maximum diameter is reached. For harvest beyond this point the feller-buncher system has to be used (thresholds for different densities are indicated by the dotted lines in the graph). Data on costs for harvesters under real conditions is not available in Austria. The assumed costs for the cut-and-chip harvester are high with 548.5 €/h and are based on ÖKL (2006) with an annual workload of 300 h for the harvester and 100 h for the header. This conservative assumption is justified with the low availability in Austria. Claas harvesters are widely spread with currently about 200 machines, but no SRF header is available (Baum, 2006). On an experimental site in Germany, a Claas harvester from a Danish company was available for 279.7 €/h including taxes. Transport costs were at 970.9 € from Denmark to Baden-Württemberg (Textor, 2003). This difference to the model value of about 50% shows the cost reduction potential once a production system is well established.

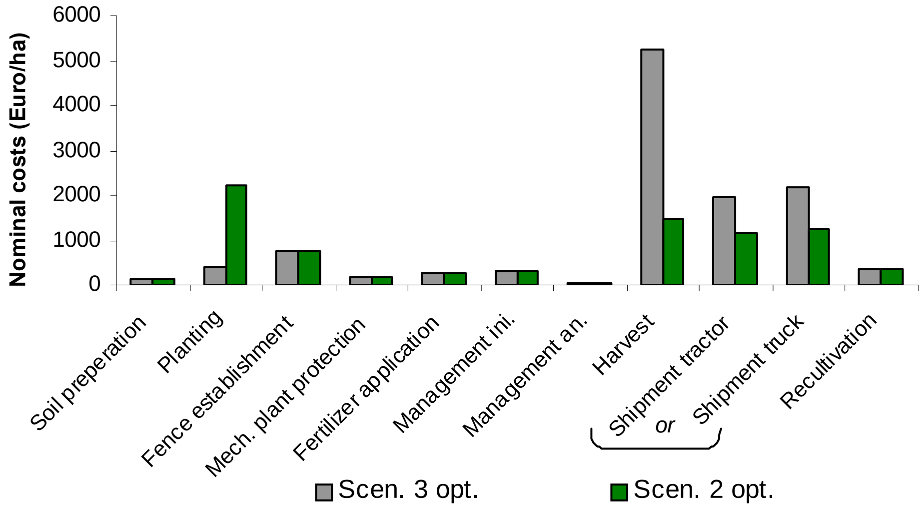


Figure 4: Nominal costs per application of *Scenarios 2 and 3 optimal.* Source: Author’s construction.

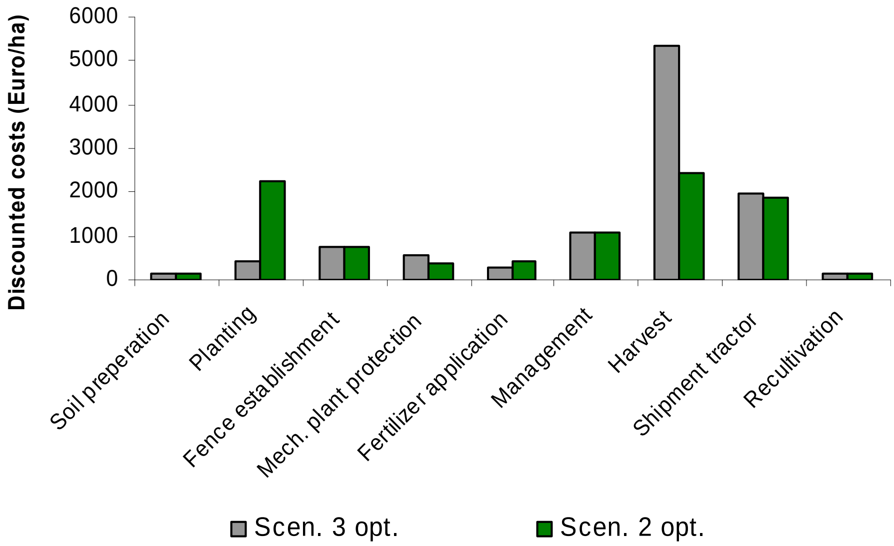


Figure 5: Discounted costs per lifespan of *Scenarios 2 and 3 optimal.* Source: Author’s construction.

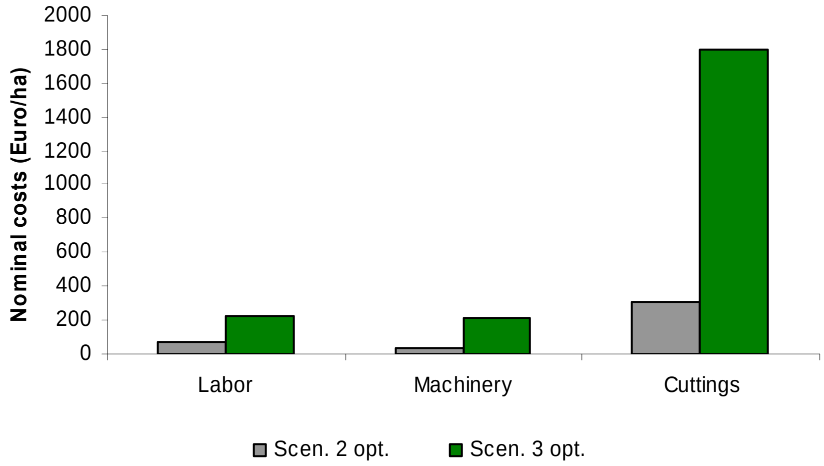


Figure 6: Composition of planting costs for *Scenarios 2 and 3 optimal.* Source: Author's construction.

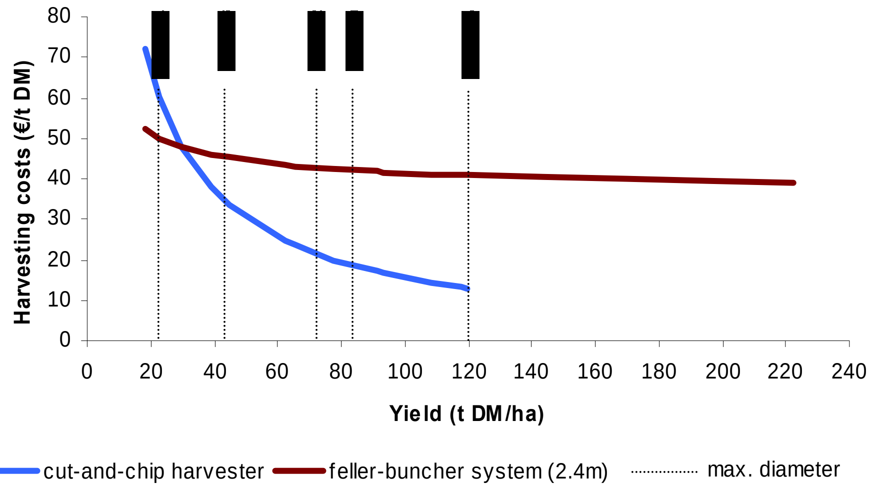


Figure 7: Relationship of harvesting costs and accumulated biomass yield. Source: Author's construction.

The cost curve of the feller-buncher harvesting system is not independent from plant density, because efficiency depends on the weight per stem and not directly on the biomass stock of the site. Lower densities cause higher stem weights for the same biomass stock and hence increase harvesting efficiency. While the cut-and-chip harvester shows a clear effect on the variation of biomass stocks, the same is not true for the feller-buncher harvesting system. The reason for this unexpected result is shown in Figure 8.

Cutting of trees by the feller-buncher harvester is only one out of three activities in order to produce wood chips. Its share on the overall costs of the whole feller-buncher harvesting system for a density of 1,736 plants/ha with a basic yield of 5 t DM is only 34%. Higher yields reduce this share and increase the relative contribution of chipping.

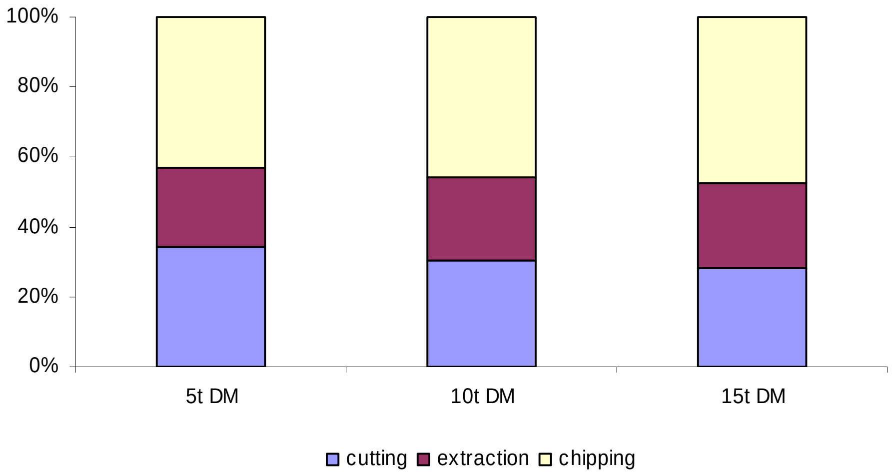


Figure 8: Composition of costs for feller-buncher harvesting system based on a density of 1,736 plants/ha and different yields. Source: Author's construction.

Chipping is the main contributor to the overall costs of the feller-buncher harvesting system. The rate of 268.79 €/h reported by Kanzian *et al*. (2006) is high in comparison to costs from other providers in Austria with about 220 €/h. The NPV of *Scenario 3 optimal* would be reduced from –1,682 €/ha to –1,236 €/ha with this lower price.

Transportation costs are the third large part of contributor to the costs of a SRF plantation. Figure 9 shows the costs of the two systems per t DM in relationship to the transportation distance. The different scenarios have similar transportation costs per unit. Variations are possible though through different sizes of the last load caused by varying harvest amounts. Trucks are cheaper from about 13 km upwards, which can be explained by a higher transportation capacity of 51 m³ freshly harvested wood chips in comparison to 36 m³ with the tractor-based system. The truck is only 4 € more expensive per hour than the tractor with two trailers and its transportation velocity is higher. On the other side, the tractor-based system does not need an additional working force for loading because it is assumed that this can be done by the driver himself. Transportation costs of the tractor-based system for 10 km are at 16.35 €/t DM, which is higher than the costs suggested by Pallast *et al*., (2005) with 13 €/t DM for the same distance.

4.3 Sensitivity Analysis

The influence of yield, wood chips price, and discount rate on the NPV is investigated with *Scenarios 2 and 3 optimal*. Figure 10 shows the impact of variations in the basic yield on the NPV. The blue line is the scenario with basic input values (basic yield 10 t DM/ha and yr). Higher yields increase the NPV of *Scenario 3 optimal* reaching –604 €/ha with 15 t. With a low yield of 5 t, NPV is at –2,692 €/ha. The NPV of *Scenario 2 optimal* does not behave the same way when yields change. With 11 t DM/ha, NPV is at –780 €/ha. Higher biomass growth then leads to the maximum diameter before harvest occurs and prevents application of the cheaper harvesting system. The NPV falls to –5,432 €/ha with 12 t and increases again with higher yields reaching –4,940 €/ha with 15 t. It becomes clear that basic growth rates can influence the optimal production system. Here, the rotation period for yields above 11 t would have to be reduced to seven years and the lifespan extended to 28 years or reduced to 22 years in order to optimize production again. The problem of discontinuities in the model becomes obvious again and has to be taken into account when discussing the results.

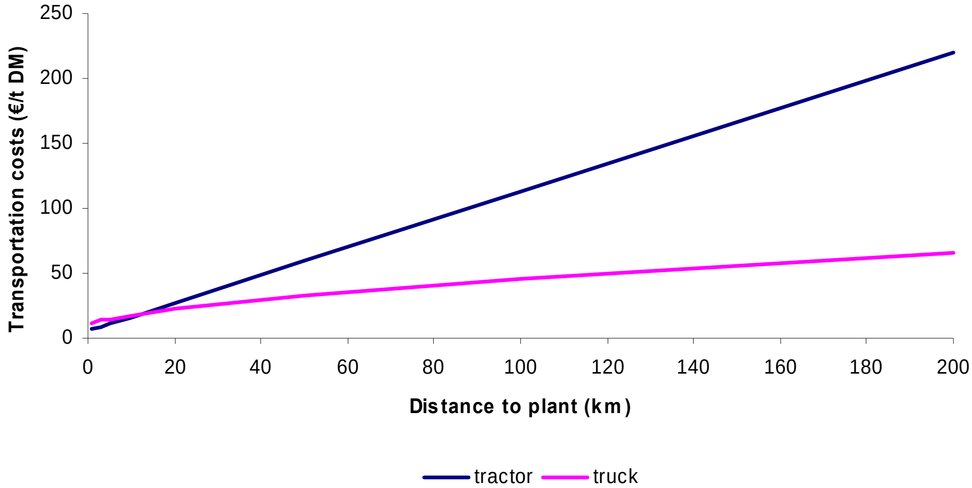


Figure 9: Transportation costs for *Scenario 2 optimal.* Source: Author's construction.

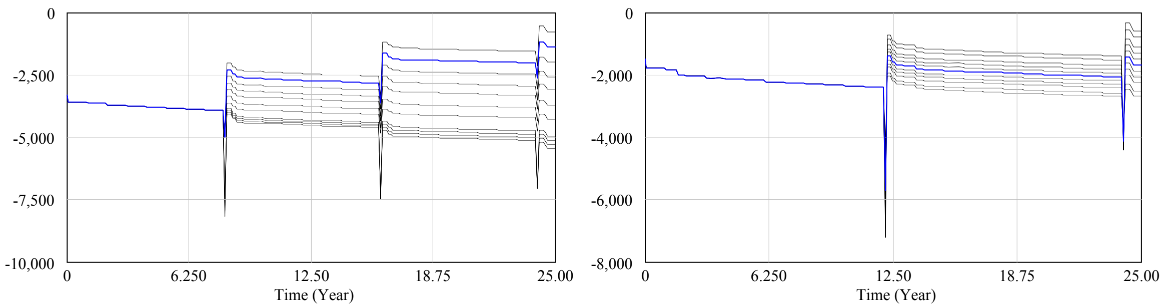


Figure 10: Sensitivity analysis for NPV (€/ha) of *Scenario 2 optimal* (left) and *3 optimal* (right); Variation in basic yield from 5 to 15 t DM/ha and yr. Source: Author's construction.

Figure 11 shows the influence of the wood chips price on the NPV. For *Scenario 2 optimal* a price of 85 €/t DM leads to a NPV of 327 €/ha. With 60 €/t, NPV reaches –2,538 €/ha. A price of 85 €/t DM for *Scenario 3 optimal* gives a NPV of 242 €/ha. With a low price of 60 €/t, NPV is at –2,964 €/ha.

The discount rate considerably influences the NPV too (Figure 12). Its nominal value for *Scenario 2 optimal* (i = 0) is at 557 €/ha and decreases to –3,310 €/ha with a discount rate of 20 %. A discount rate of 0 in *Scenario 3 opt.* gives a NPV of –1,099 €/ha. It decreases to –2,046 with a discount rate of 20%. With a variation in NPV of 3,867 €, *Scenario 2 optimal* is much more sensitive to changes of the discount rate than *Scenario 3 optimal* with a variation of 947 €/ha.

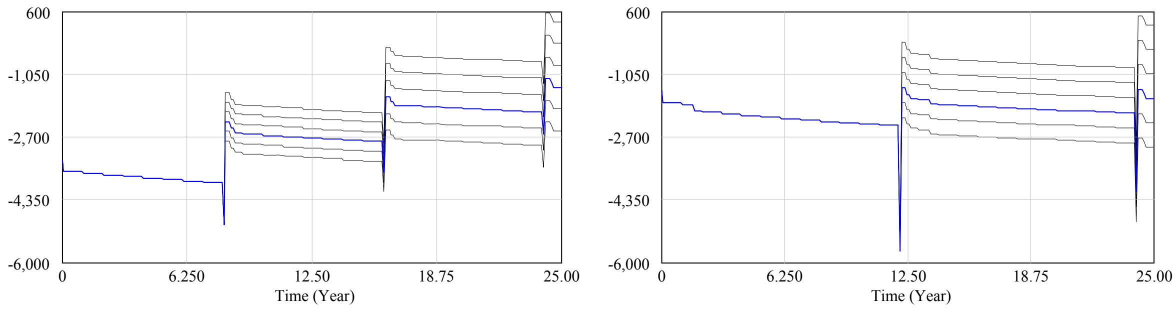


Figure 11: Sensitivity analysis for NPV ((€/ha) of *Scenario 2 optimal* (left) and *3 optimal* (right); Variation in wood chips price from 60 to 85 €/t DM. Source: Author's construction.

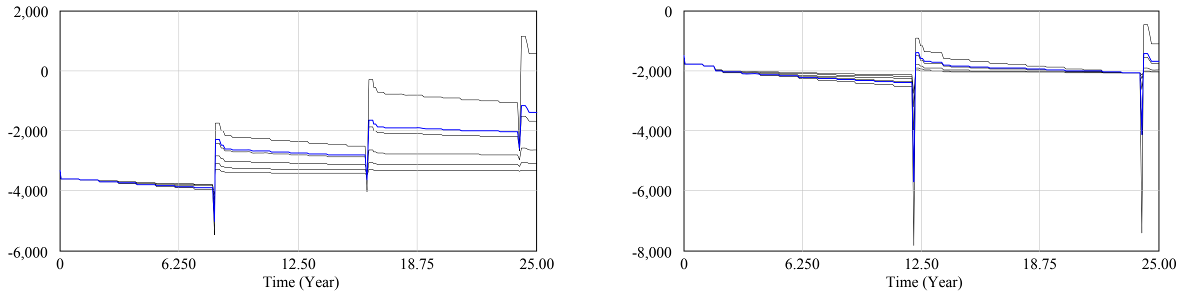


Figure 12: Sensitivity analysis for NPV (€/ha) of *Scenario 2 optimal* (left) and *3 optimal* (right); Variation in discount rate from 0 to 20% per year. Source: Author's construction.

In any case were future benefits are higher than costs, a decreasing discount rate will increase the NPV. In forestry, increasing discount rates generally decrease the rotation period because future benefits become less valuable and must be consumed earlier in order to maximize the net present value. In addition, the size of net present value decreases as well (for examples see Creedy and Wurzbacher, 2001). Figure 13 shows declining NPV with increasing discount rates. However, the first effect of more favorable shorter rotation periods caused by higher discount rates cannot be observed according to the model results.

With a discount rate of 0%, the highest NPV of 557 €/ha for *Scenario 2 optimal* is followed by *Scenario 3 optimal* with –1,099 €/ha. A discount rate of 10% changes the situation. NPV of *Scenario 3 optimal* reaches –1,968 €/ha and is higher than that of *Scenario 2 optimal* with –2,634 €/ha. Increasing discount rates cause future net benefits to decline, while the present costs stay the same. This effect favors scenarios with low site establishment costs, which are those with lower plant densities for longer rotation periods. Obviously, the effect declines with decreasing importance of site establishment costs, achieved for example with lower prices for planting materials.

Storage in the model has three direct effects on the NPV. It causes high biomass decay rates of wood chips, but does not reduce water contents. The quality of wood chips declines and reduces the NPV depending on the length of the storage period. Storage of whole stems leads to drying effects, which raises the price of wood chips and reduces transportation costs if the weight of product is limiting. Biomass decay for whole stems is comparably low. The third effect is a reduction in income caused by discounting of the delayed payments. Effects of storage on NPV are presented in Figure 14 for *Scenarios 2 and 3 optimal*. The cut-and-chip harvesting system of *Scenario 2 optimal* causes biomass losses. Its NPV falls by 100% after about nine months of storage. Storage of whole stems (*Scenario 3 optimal*), on the other side, leads to a higher heating value of wood and therefore increases the wood chips price in the model. Maximum drying effect is reached after eight months with a NPV of about 974 €/ha. The wood chips price in this scenario is at 93 €/t DM. If *Scenario 2 optimal* would have been harvested with the feller-buncher harvester, positive storage effects would be achievable. After eight months the NPV would be at –3,277 €/ha, which is 517 € lower than the NPV obtained with the cut-and-chip harvesting system.

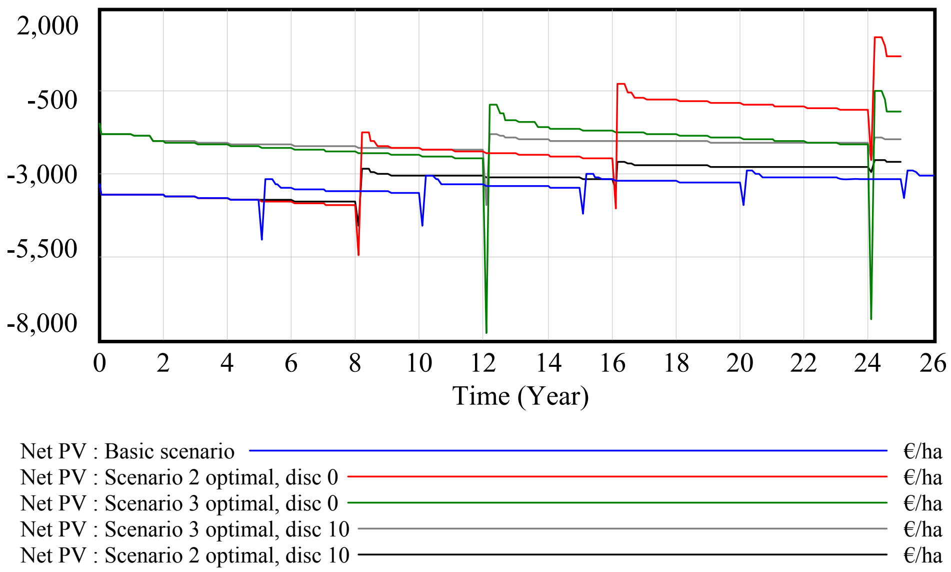


Figure 13: Effect of discount rate on the NPV of *Scenarios 2 and 3 optimal*. Source: Author's construction.

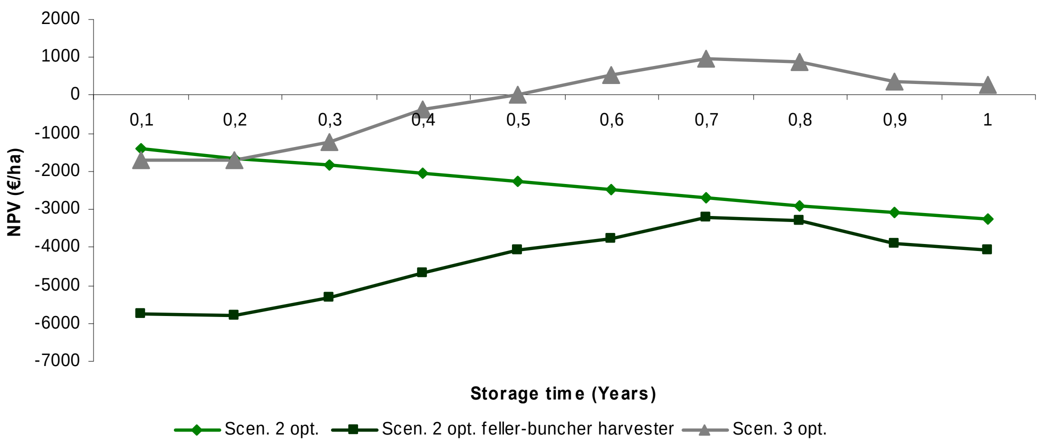


Figure 14: Influence of storage on NPV of *Scenarios 2 and 3 optimal*. Source: Author's construction.

4.4 Best and Worst Case Scenarios

Investment decisions on projects with a long lifespan of 25 to 30 years need the consideration of changes in input costs. Technical improvements, change of prices for inputs and outputs, and the possible policy framework all have to be taken into account. A comparison of optimistic and pessimistic scenarios can help to anticipate the future and shows the spectrum of possible outcomes of a decision. Figure 15 presents NPVs of *Scenarios 2 and 3 optimal* and its extreme scenarios with the changes in parameter values according to Table 1.

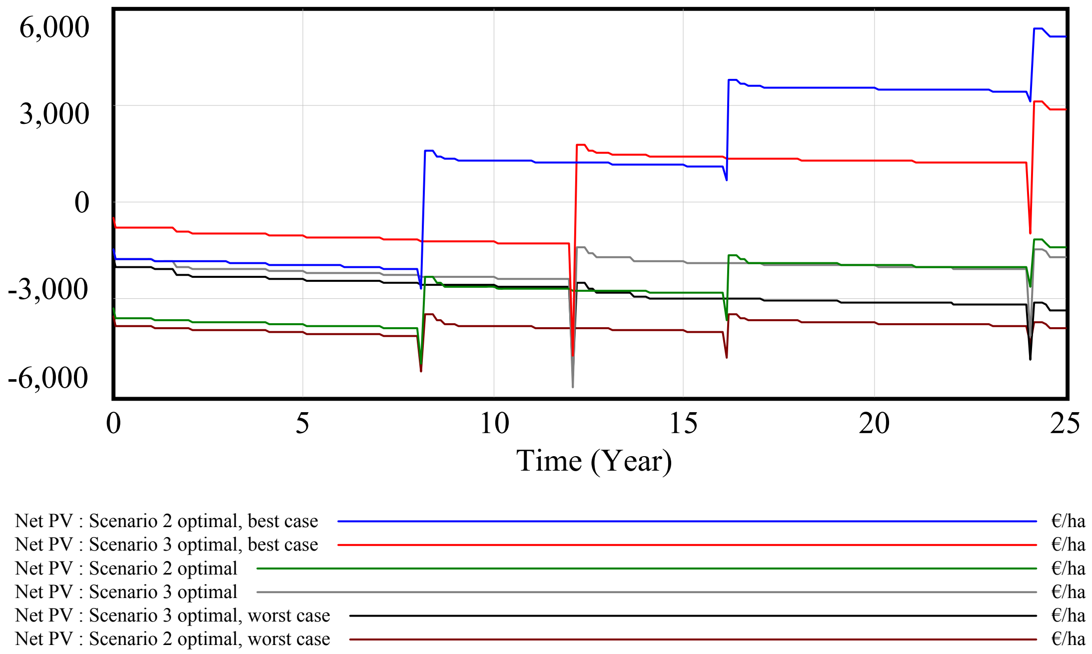


Figure 15: NPV of *Scenarios 2 and 3 optimal* with extreme input and output parameter values. Source: Author's construction.

Table 1: Input parameters for best and worst case scenarios. Source: Author's construction.

Variation of parameters	Unit	Best case	Worst case
Initial biomass growth	t DM/ha	13	8
Wildlife damage	% of biomass stock	1	0
Reduction after second harvest	% of stock	0	10
Costs for cuttings	€/cutting	0.08	0.16
Costs for fence	€/ha	0	1000
Number of maintenance after harvest	-	1	5
Claas Jaguar costs	€/h	280	548.5
Claas Jaguar larger diameter harvest	-	yes	no
Multiple stem harvest for feller-buncher	-	yes	no
Chipping costs	€/h	220	268
Tractor and trailer ($18 m^3$)	€/h	41	58
Price for product	€/t DM	80	60

Based on optimistic input parameter values, a NPV of 5,135 €/ha for *Scenario 2 optimal best case* and 2,851 for *Scenario 3 optimal best case* can be reached through lower site establishment (low price for cuttings, no fence needed) and maintenance costs.

Technical improvements in harvest machinery tolerate larger maximum diameters for the cut-and-chip harvester and multiple stem harvest for the feller-buncher harvester. Prices for wood chips are relatively high with 80 €/t DM. The worst case scenario is more or less based on the basic input parameter values. The price for the product and the yield are lower. More intense maintenance is necessary and fence establishment is more expensive. In addition, a 10% reduction of the current biomass growth rate after the second harvest for each further rotation is assumed. NPV falls to –3,327 €/ha for *Scenario 3 optimal worst case* and to –3,899 €/ha for *Scenario 2 optimal worst case*. The high variation between best and worst case scenarios again shows the sensitivity of the NPV on specific parameters and hence the great uncertainties related to the profitability calculation. With a difference of 9,034 €/ha, *Scenario 2 optimal* again is more sensitive on changes in parameters than *Scenario 3 optimal*. This can be explained by the fact that the input and output intensive production system gains relatively more from changes in prices than the input extensive system.

The need for taking out land from production of food and feedstock in order to receive subsidies created an economically favorable environment for the production of non-food crops like wood on arable land. If SRF plantations are established on agricultural land outside the set-aside requirements, opportunity costs for land emerge. In general, the EU energy crop premium is available for this land. It is currently at 45 €/ha. Subsidies for site establishment are also available in some European countries and are imaginable for Austria too. Figure 16 presents the influences of opportunity costs for land and subsidies on the NPV of *Scenarios 2 and 3 optimal best case*. NPV of *Scenario 2 optimal best case* can offset land use costs of about 300 €/ha until it becomes negative.

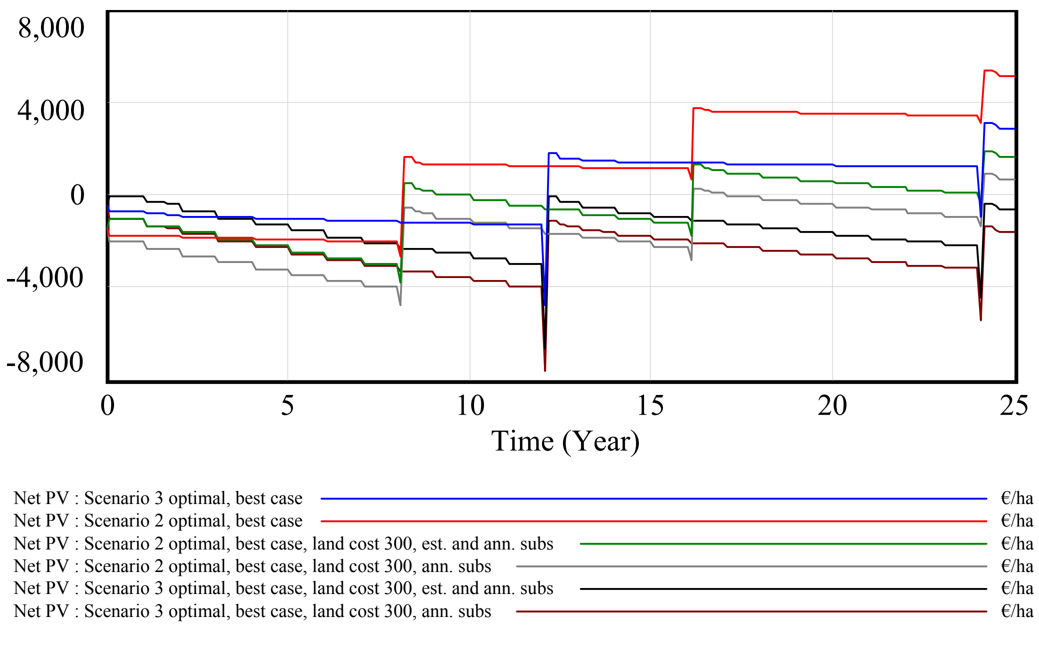


Figure 16: NPV of *Scenarios 2 and 3 optimal best case* with and without land use costs and subsidies. Source: Author's construction.

With subsidies of 1,000 €/ha for site establishment and an annual subvention of 45 €/ha, NPV increases to 1,647 €/ha. NPV of *Scenario 3 optimal best case* becomes negative with land use costs of 300 €/ha even if a site establishment and annual subventions are paid.

Production costs per unit are an important figure for a comparison of SRF with other sources of biomass or for price discussions. In Figure 17, production costs per t DM of sold product (excluding harvest, storage, and shipment losses) under *Scenarios 2* and *3 optimal* as well as *Scenarios 2* and *3 optimal best case* are presented. Costs for shipment are not included, but can be added using Figure 9. Production costs of *Scenarios 2 optimal* and *2 optimal best case* fall with increasing yields until the maximum diameter for the cut-and-chip harvester is reached. At this point, 11 t DM/ha and year for *Scenario 2 optimal* and 13 t for *Scenario 2 optimal best case*, costs increase rapidly and afterwards fall again. Production costs per unit of *Scenario 2 optimal* are lower than those for *Scenario 3 optimal* only for a yield of about 10 t DM/ha. Lower yields reduce the productivity of the harvesting system and higher yields prevent using the cut-and-chip harvester. This changes for the best case scenarios. *Scenario 2 optimal best case* is cheaper per unit from a yield of about 5 t until the maximum diameter is reached before harvest with an actual yield of about 13 t DM/ha. With yields of around 10 t DM/ha, costs per unit of sold product are between 20 and 33 €.

$$C_{prod,n} = 133.18 * Y_n^{-0.5509} \quad (7)$$

Equation (7) with $R^2=0.975$ is derived from *Scenario 3 opt.* and gives a rough estimate for production costs on site n ($C_{prod,\ n}$) based on the actual, not basic, biomass yield (Y_n).Its shape is indicated by the black line in Figure 17.

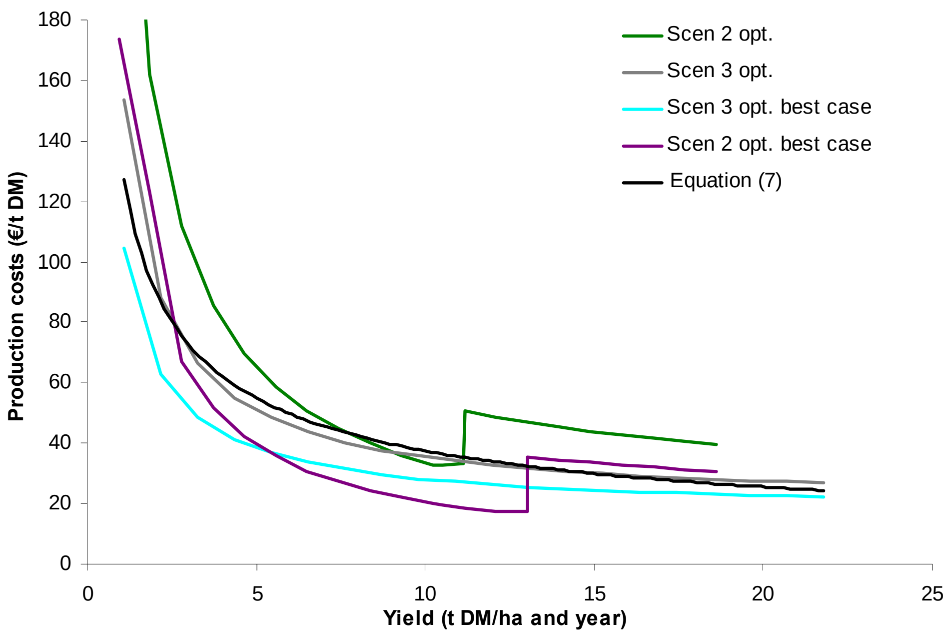


Figure 17: Production costs per sold unit (excluding shipping) of different scenarios. Source: Author's construction.

Opportunity costs for land must be considered if the SRF site competes with other crops. Competitiveness only is realistic for optimized production systems, which could be the best case scenarios. Figure 18 presents production costs per sold unit for *Scenarios 2 and 3 optimal best case*. It again shows the considerable influence of land use costs.

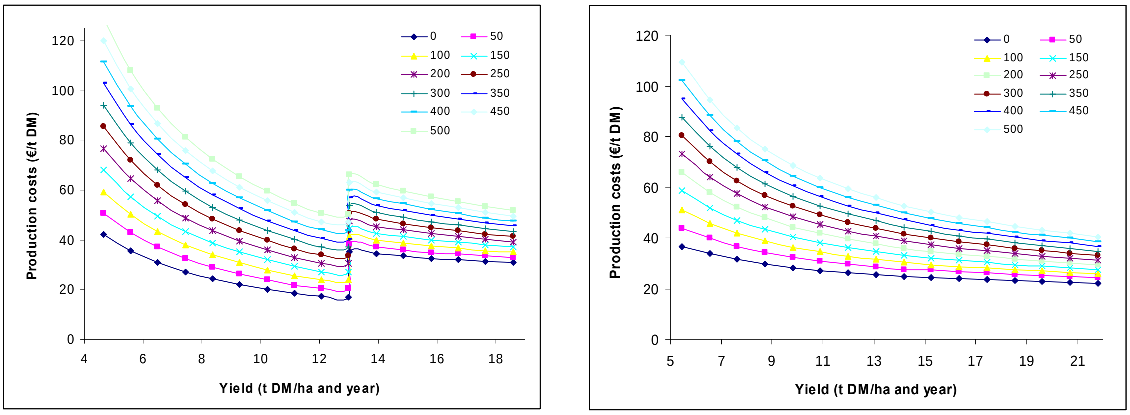


Figure 18: Production costs (excluding shipping) per sold unit of *Scenarios 2* (left) *and 3 optimal best case* (right) under different opportunity costs for land in €/ha and year. Source: Author's construction.

Production costs of *Scenario 2 optimal best case* increase from 17 € per t DM for a yield of 13 t DM/ha and year and zero opportunity costs for land to 50 € with annual land costs of 500 €/ha. Costs per sold unit under *Scenario 3 optimal best case* and the same yield increase from 26 € to 56 €/t DM. The influence of land costs on the overall production costs declines with increasing yields.

5 Conclusions

This study investigated the profitability of SRF on agricultural land in Austria. Concepts from system dynamics helped to model the complex biological interrelationships of SRF plantations. Effects of these relationships on the profitability were the main focus of this study. Absolute values, though interesting, strongly depend on the assumed input parameters (see, for example, Figure 15) and are only of partial relevance here. For farmers, the NPV is an interesting figure to prove the profitability of investments. Farm specific conditions decide about further criteria. Income from labor and the contribution margin used to pay back investments into machinery are of interest too. This study focused solely on the production of poplar. An extension of the model to include other species, e.g., willow, would provide valuable insights into the competitiveness of different species. The same is true for further planting and harvesting methods.

It has been proven that SRF plantations can be profitable to agricultural entrepreneurs under optimistic assumptions. NPVs reach up to 4,300 €/ha under these scenarios and can compete with other land uses. However, the currently low developed market structures for SRF in Austria challenge these assumptions.

Optimization showed that various production concepts, based on different plant densities and rotation periods, have similar NPV and are specific to the yield potential of the site. Shorter rotation periods have higher investment costs, but also higher returns during the project period. They are based on denser stands, which cause annual yields to decrease earlier and faster after MABI was reached. This reduces adjustment possibilities of plantation holders to product prices and environmental conditions during harvest time. Additionally, more frequent harvest might cause higher soil compaction and decrease the environmental value of the site. Nutrients extraction is higher for shorter rotation periods caused by the higher share of bark and branches. Stress for trees through more frequent harvest is higher and can cause increased death rates of stools and higher susceptibility for diseases and pests. Input and output intensive sites (higher plant densities and shorter rotation periods) are more sensitive to changes in input parameters. Uncertainties on future developments in input and output markets and related risks can be reduced by investing into less intensive production systems (compare with Figures 10 and 15). The current trend towards rotation periods of below five years has to be discussed also on basis of these arguments.

As results have shown, there are good reasons to invest also into the further development of whole stem harvesting techniques including extraction and chipping, which allow efficient harvest of older stands with lower plant densities.

Depending on storage conditions and the property of the harvested product, storage of wood can cause high biomass losses for wood chips on the one side and significant increases in product quality for whole stems on the other. A combination of cheap cut-and-chip harvesting techniques and drying facilities for wood chips can bring about a cheaply produced product with a high heating value. Excess heat of biomass power plants or torification of wood chips can be interesting options, which need further research efforts.

Ceuleman and Deraedt (1999) see genotypes and cultural management as the main components of productivity of SRF plantations. Site-specific yield potentials based on climate, soil and other factors are important as well. The variability among clones is extremely high for SRF species. Site-specific experiments under varying rotation periods and plant densities are necessary for the available clones. Data from these experiments then is the starting point for the economic optimization of SRF production. Currently, the trend towards shorter rotation periods and the long periods of time needed for obtaining results cause data from long term studies on SRF plantations to be underrepresented.

SRF is already an interesting option for the production of biomass on agricultural land. Beside possible positive environmental effects, it is economically profitable under specific conditions. Further research is needed in order to reduce the great uncertainties, which are still related to its production. Furthermore, the creation of well established markets for supply of input materials as well as product demand would help to spread it even more in agriculture.

References

AWI (2005). Costs for Agricultural Input Products. Available at: http://www.awi.bmlf.gv.at/ (accessed 31 August 2006).

Baum, F. (2006). Personal communication, 12 July.

Börjesson, P. (1999). Environmental Effects of Energy Crop Cultivation in Sweden—I: Identification and Quantification. *Biomass and Bioenergy* **16**, 137–154.

Burger, F. (2006). Personal communication, 8 August.

Burger, F. and V. Scholz (2004). Stand der Technik bei der Ernte von Energiewäldern. *Holz-Zentralblatt* **46**, 610–611 (in German).

Burger, F. and W. Sommer (2005). Erntetechnik für Energiewälder. *Forst und Technik* **4**, 6–8 (in German).

Ceulemans, R. and W. Deraedt (1999). Production Physiology and Growth Potential of Poplars Under Short-rotation Forestry Culture. *Forest Ecology and Management* **121**, 9–23.

Claas Deutschland (2006). Jaguar Holzhäcksel. Available at: http://www.claas.com/countries/generator/cl-pw/de/products/fh/haecksel/start.lang=de_DE.html (accessed 18 August 2006).

Creedy, J. and A.D. Wurzbacher (2001). The Economic Value of a Forested Catchment with Timber, Water and Carbon Sequestration Benefits. *Ecological Economics* **38**, 71–83.

EEA (2006). How Much Bioenergy Can Europe Produce Without Harming the Environment? EEA Report No 7. European Environment Agency (EEA), Copenhagen, Denmark.

Friedrich, E. (1999). Anbautechnische Untersuchungen in forstlichen Schnellwuchsplantagen und Demonstration des Leistungsvermögens schnellwachsender Baumarten. In: A. Schütte, *Modellvorhaben "Schnellwachsende Baumarten"*. Zusammenfassender Abschlussbericht. Schriftenreihe "Schnellwachsende Rohstoffe" Band 13. Landwirtschaftsverlag, Münster, Germany, 19–150.

Gigler, J.K., W.K.P. van Loon, J.V. van den Berg, C. Sonneveld, and G. Meerdink (2000). Natural Wind Drying of Willow Stems. *Biomass and Bioenergy* **19**, 153–163.

Hartmann, H. And K. Thuneke (1997). Ernteverfahren für Kurzumtriebsplantagen—Maschinenerprobung und Modellbetrachtungen. Landtechnik Bericht, Heft 29, Selbstverlag Landtechnik Weihenstephan, Freising, Germany (in German).

Heaton, R.J., P.F. Randerson and F.M. Slater (1999). The Economics of Growing Short Rotation Coppice in the Uplands of Mid-Wales and an Economic Comparison with Sheep Production. *Biomass and Bioenergy* **17**, 59–71.

Heiss, M. (2006). Auf Kurzumtriebsflächen erzielbare Deckungsbeiträge in Österreich. Energieholz. Kosten der Energieholzbereitstellung, Kurzumtrieb und Durchforstung. Fachtagung Wieselburg, 4 November 2005 (in German).

Heller, M.C., G.A. Keoleian and T.A. Volk (2003). Life Cycle Assessment of a Willow Bioenergy Cropping System. *Biomass and Bioenergy* **25**, 147–165.

Herve, C. and R. Ceulemans (1996).Short-rotation Coppiced vs. Non-coppiced Poplar: A Comparative Study at Two Different Field Sites. *Biomass and Bioenergy* **2** (3), 139–150.

Hofmann, M. (2005). Pappeln als nachwachsender Rohstoff auf Ackerstandorten—Kulturverfahren, Ökologie und Wachstum unter dem Aspekt der Sortenwahl. Schriften des Forschungsinstituts für schnellwachsende Baumarten, Band 8, Hann, Münden, Germany (in German).

Jirjis, R. (2005). Effects of Particle Size and Pile Height on Storage and Fuel Quality of Comminuted Salix Viminalis. *Biomass and Bioenergy* **28**, 193–201.

Kanzian, C., B. Fenz, F. Holzleitner and K. Stampfer (2006). Waldhackguterzeugung aus Schlagrücklass. Fallbeispiele im Laub- und Nadelholz. Institut für Forsttechnik. Universität für Bodenkultur (BOKU), Vienna, Austria.

Kauter, D., I. Lewandowski and W. Claupein (2003). Quantity and Quality of Harvestable Biomass from Populus Short Rotation Coppice for Solid Fuel Use—A Review of the Physiological Basis and Management Influences. *Biomass and Bioenergy* **24**, 411–427.

Kopp, R.F., L.P. Abrahamson, E.H. White, T.A. Volk, C.A. Nowak and R.C. Fillhart (2001). Willow Biomass Production During Ten Successive Annual Harvests. *Biomass and Bioenergy* **20**, 1–7.

Makeschin, F. (1999). Short Rotation Forestry in Central and Northern Europe—Introduction and Conclusions. *Forest Ecology and Management* **121**, 1–7.

Mayer, K. (2006). Personal communication, 5 July.

MIT System Dynamics Group (2006). What is System Dynamics? Available at: http://web.mit.edu/sdg/www/what_is_sd.html (accessed 21 August 2006).

Mitchell, C.P. (1995). New Cultural Treatments and Yield Optimization. *Biomass and Bioenergy* **9** (1–5), 11–34.

Mitchell, C.P., E.A. Stevens and M.P. Watters (1999). Short-rotation Forestry—Operations, Productivity and Costs Based on Experience Gained in the UK. *Forest Ecology and Management* **121**, 123–136.

Niederösterreicher Waldverband (2006). Holz-Nettopreise. Anfang August. Available at: http://www.waldverband-noe.at/content/service/index.php (accessed 22 August 2006) (in German).

ÖKL (2006). Online-Richtwerte für Landwirtschaft. Available at: http://richtwerte.oekl.at/ (accessed 27 August 2006) (in German).

Pallast, G., T. Breuer and K. Holm-Müller (2005). Schnellwachsende Baumarten—Chance für zusätzliches Einkommen im ländlichen Raum. Discussion Paper 3. Institute for Agricultural Policy, Market Research. University of Bonn, Germany (in German).

Pelzmann, G. (1992). Fallstudien zum Energieholzanbau in der Steiermark. Dissertation. Universität für Bodenkultur (BOKU) Vienna, Austria (in German).

Perlack, R.D., M.E. Walsh, L.L. Wright and L.D. Ostlie (1996). The Economic Potential of Whole-tree Feedstock Production. *Bioresource Technology* **55**, 223–229.

Raschka, H.-D. (1997). Forstliche Biomasseproduktion im Kurzumtrieb—Abschlussbericht des Forschungsprojektes P/2/24—“Versuche für die Produktion forstlicher Biomasse-Kurzumtriebsversuche”. Forstlichen Bundesversuchsanstalt (FBVA) Berichte Nr. 97/1997 (in German).

Rosenqvist, H. and M. Dawson (2005). Economics of Willow Growing in Northern Ireland. *Biomass and Bioenergy* **28**, 7–14.

SAC (2000). Energy from Willow. Scottish Agricultural College (SAC), Edinburgh, United Kingdom.

Sächsische Landesanstalt für Landwirtschaft (2004). Anbauempfehlungen für schnellwachsende Baumarten. Fachmaterial. Available at: http://www.smul.sachsen.de/lfl/publikationen/download/858_1.pdf (accessed 16 August 2006) (in German).

Scholz, V. (2005). Schimmelpilzentwicklung und Verluste bei der Lagerung von Holzhackschnitzeln. *Holz als Roh-und Werkstoff* **63**, 449–455 (in German).

Schönhart, M. (2006). Revegetation—An Option to Mitigate Climate Change for Austria? Diploma Thesis, University of Natural Resources and Applied Life Sciences Vienna, Austria.

Senelwa, K. and R.E.H. Sims (1999). Fuel Characteristics of Short Rotation Forest Biomass. *Biomass and Bioenergy* **17**, 127–140.

Spinelli, R. and P. Kofman (1996). A Review of Short-Rotation Forestry Harvesting in Europe. Paper presented at the First Conference of the Short Rotation Woody Crops Operations Working Group, Paducah, KY, 23–25 September, 1996.

Spinelli, R., C. Nati, C. and N. Magagnotti (2006a). Biomass Harvesting from Buffer Strips in Italy: Three Options Compared. *Agroforestry Systems* **26**, 1–9.

Spinelli, R., B.R. Hartsough, P.M.O Owende and S.M. Ward (2006b). Productivity and Cost of Mechanized Whole-Tree Harvesting of Fast-Growing Eucalypt Stands. *International Journal of Forest Engineering* **13 (**2).

Sterman, J.D. (2000). *Business Dynamics. Systems Thinking and Modeling for a Complex World*. Irwin McGraw-Hill, Boston, USA. ISBN 0-07-231135-5.

Strong, T. and E. Hansen (1993). Hybrid Poplar Spacing/Productivity Relations in Short Rotation Intensive Culture Plantations. *Biomass and Bioenergy* **4**, 255–261.

Textor, B. (2003). Anbau, Bereitstellung und energetische Nutzung von Pappeln im Kurzumtrieb. (Praxisversuch 1991–2001). Auszug aus dem Abschlussbericht der vollmechanisierten (2.) Beerntung 2001. Forstliche Versuchs- und Forschungsanstalt Baden-Württemberg, Abteilung Waldnutzung. Freiburg, Germany (in German).

Tharakan, P.J., T.A. Volk, L.P. Abrahamson and E.W. White (2003). Energy Feedstock Characteristics of Willow and Hybrid Poplar Clones at Harvest Age. *Biomass and Bioenergy* **25**, 571–580.

Toivonen, R.M. and L.J. Tahvanainen (1998). Profitability of Willow Cultivation for Energy Production in Finland. *Biomass and Bioenergy* **15**, 27–37.

Traupmann, P. (2004). Anleitung zur Anlage von Kurzumtriebsflächen. Bioenergie Burgenland. Available at: http://www.fpp.at/pics/download/fpp_kurzumtrieb_end fassung_081104.pdf#search=%22Kurzumtrieb%20%22 (accessed 28 August 2006) (in German).

Trinkaus, P. (1998). Short-rotation Forestry: Discussion of 10 Austrian Principles from the Viewpoint of Preservation of Environment and Nature. *Biomass and Bioenergy* **15 (**1), 109–114.

Weigelt, H. (2006). Ernte von Kurzumtriebswäldern (Weiden, Pappeln). Jaguar Holzhäckseltechnik. Vorträge im Rahmen der Tagung "Bioenergie vom Acker" am 9. März 2006 in Landwirtschaftszentrum Schloss Eichhof Bad Hersfeld (in German).

Weih, M. (2004). Intensive Short Rotation Forestry in Boreal Climates: Present and Future Perspectives. *Canadian Journal of Forest Research* **34**, 1369–1378.

Appendices

Appendix 1: Biomass Growth Multiplication Factors

Spacing (m x m)			Year 1	2	3	4	5	6	7	8	9	10
	0.6x0.6	**Mulipl. Factor**	*0.1*	0.2	0.6	0.9	1.0	*1.1*	*1.0*	*1.0*	*0.9*	*0.8*
		Ann. gr. (t DM/ha*yr)	*0.9*	2.7	11.1	16.5	13.8	*12.8*	*5.2*	*4.0*	*3.0*	*2.0*
		MABI (t DM/ha*yr)	*0.9*	1.8	4.9	7.8	9.0	*9.6*	*9.0*	*8.4*	*7.8*	*7.2*
	1.0x1.0	**Mulipl. Factor**	*0.0*	*0.2*	*0.4*	*0.8*	*0.9*	*1.0*	*1.0*	*0.9*	*0.9*	*0.9*
		Ann. gr. (t DM/ha*yr)	*0.3*	*2.9*	*7.9*	*15.6*	*12.3*	*12.7*	*7.1*	*5.1*	*9.2*	*4.9*
		MABI (t DM/ha*yr)	*0.3*	*1.6*	*3.7*	*6.7*	*7.8*	*8.6*	*8.4*	*8.0*	*8.1*	*7.8*
	1.2x1.2	**Mulipl. Factor**	*0.1*	0.2	0.4	0.7	0.8	0.9	0.9	0.9	1.0	0.9
		Ann. gr. (t DM/ha*yr)	*0.8*	2.3	6.2	15.1	11.6	12.6	8.1	5.7	12.3	6.3
		MABI (t DM/ha*yr)	*0.8*	1.5	3.1	6.1	7.2	8.1	8.1	7.8	8.3	8.1
	1.8x1.8	**Mulipl. Factor**	*0.0*	0.0	0.1	0.4	0.7	0.8	0.9	0.9	1.0	1.0
		Ann. gr. (t DM/ha*yr)	*0.1*	0.3	2.3	11.7	16.1	8.5	12.8	9.0	17.5	6.7
		MABI (t DM/ha*yr)	*0.1*	0.2	0.9	3.6	6.1	6.5	7.4	7.6	8.7	8.5
	2.4x2.4	**Mulipl. Factor**	*0.0*	0.0	0.1	0.2	0.3	0.4	0.6	0.8	0.9	1.0
		Ann. gr. (t DM/ha*yr)	*0.1*	0.3	1.7	4.3	6.1	10.3	11.5	20.9	13.2	14.6
		MABI (t DM/ha*yr)	*0.1*	0.2	0.7	1.6	2.5	3.8	4.9	6.9	7.6	8.3

Spacing (m x m)			Year 11	12	13	14	15	16	17	18	19	20
	0.6x0.6	**Mulipl. Factor**	*0.8*	*0.7*	*0.7*	*0.6*	*0.6*	*0.5*	*0.5*	*0.5*	*0.4*	*0.4*
		Ann. gr. (t DM/ha*yr)	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
		MABI (t DM/ha*yr)	*6.6*	*6.1*	*5.6*	*5.2*	*4.9*	*4.6*	*4.3*	*4.1*	*3.8*	*3.7*
	1.0x1.0	**Mulipl. Factor**	*0.9*	*0.8*	*0.8*	*0.7*	*0.7*	*0.6*	*0.6*	*0.6*	*0.5*	*0.5*
		Ann. gr. (t DM/ha*yr)	*3.7*	*2.7*	*2.0*	*1.3*	*0.7*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
		MABI (t DM/ha*yr)	*7.4*	*7.0*	*6.6*	*6.3*	*5.9*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*
	1.2x1.2	**Mulipl. Factor**	*0.9*	*0.9*	*0.8*	*0.8*	*0.7*	*0.7*	*0.7*	*0.6*	*0.6*	*0.6*
		Ann. gr. (t DM/ha*yr)	*5.0*	*4.0*	*3.0*	*2.0*	*1.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
		MABI (t DM/ha*yr)	*7.8*	*7.5*	*7.2*	*6.8*	*6.4*	*6.0*	*5.6*	*5.3*	*5.1*	*4.8*
	1.8x1.8	**Mulipl. Factor**	1.0	1.0	*1.0*	*0.9*	*0.9*	*0.9*	*0.9*	*0.8*	*0.8*	*0.7*
		Ann. gr. (t DM/ha*yr)	6.3	8.3	*7.3*	*6.0*	*5.0*	*4.0*	*3.0*	*2.0*	*1.0*	*0.0*
		MABI (t DM/ha*yr)	8.3	8.3	*8.2*	*8.1*	*7.9*	*7.6*	*7.3*	*7.1*	*6.7*	*6.4*
	2.4x2.4	**Mulipl. Factor**	1.1	1.1	1.1	1.0	1.1	1.1	*1.1*	*1.1*	*1.1*	*1.1*
		Ann. gr. (t DM/ha*yr)	18.2	11.6	9.4	3.8	12.0	15.6	*9.6*	*9.6*	*9.6*	*9.6*
		MABI (t DM/ha*yr)	9.2	9.4	9.4	9.0	9.2	9.6	*9.6*	*9.6*	*9.6*	*9.6*

Source: Author's compilation based on Strong and Hansen (1993).

Biomass multiplication factors are derived from Strong and Hansen (1993) for poplar clone NC-5260. Data for spacing 1.2, 1.8, and 2.4 are from the same site and years. Spacing 0.6 was taken from another location during the same investigation period. Data for spacing 1.0 was created by interpolation from values for spacing 0.6 and 1.2. Annual growth rates and multiplication factors are derived from MABI. For year 1, no data was published. Hence, half of MABI from year 2 was taken. Data for spacing 0.6 is only available over a four-year period. The value for year 6 is derived from published data on clone NE-299. In year 5, it had a yield 7% above clone NC-5260. For years 6 and 7, data from NE-299 was taken and reduced by 7%. Data for all clones after the last published record were derived by a steady reduction of annual growth rates, which reduces MABI accordingly. Data in italic letters indicates modification. A further study on the effects of spacing and rotation period on biomass yields is presented by Friedrich (1999). It only considers a period of eight years. Although different absolute values, yields based on spacing and rotation period behaved the same way. They are higher for higher densities, but the differences decline with increasing rotation periods. Yields from sites with higher densities level off earlier.

Appendix 2: Important Input Values for Cost Calculation of *Basic Scenario*

General factors	***Value***	***Unit***	***Source***
Labor costs	10	€/h	
Discount rate	4	%	
Weight of wood chips	0.38	t FM/m^3	Hartmann and Thuneke (1997) and Spinelli, Nati and Magagnotti (2006)
Rotation period	5	yr	
Plantation life time	25	yr	
Basic yield	10	t DM/ha and yr	
Plant density	10,000	plants/ha	

Establishment cost factors			***Source***
Time for soil preparation	2.4	h/ha	
Costs for soil preparation	105	€/h	ÖKL (2006)
Costs for cuttings	0.18	€/cutting	Mayer (2006)
Planting time	0.001	h/(2 cuttings)	
Planting time manipulation factor	0.2	of net-planting time	
Planting machinery costs	35.5	€/h	ÖKL (2006)
Persons needed for planting	3		
Controlling of planting	4	h/ha	
Costs for fence	765	€/ha	
Establishment management	30	h/ha	

Maintenance cost factors			***Source***
Number of maintenance after harvest	3		
Maintenance time	1	h/ha	
Maintenance costs	32	€/h	ÖKL (2006)
Manual maintenance	5	h/ha	
Annual management	5	h/ha	
Nitrogen fertilizer	0.59	€/kg	AWI (2005)
Phosphorus fertilizer	0.68	€/kg	AWI (2005)
Potassium fertilizer	0.3	€/kg	AWI (2005)
Fertilizer application machinery costs	29.4	€/h	ÖKL (2006)
Fertilizer application time	1	h/ha	

Harvest cost factors			***Source***
Claas Jaguar costs	548.5	€/h	ÖKL (2006)
Tractor and trailer (18m^3)	58	€/h	ÖKL (2006)
Claas harvest interruptions	20	% of NP_{Claas}	Average from Hartmann and Thuneke (1997)
Time for row change Claas	0.009	h/row	Hartmann and Thuneke (1997)
Claas harvest losses	4.6	% of Y_{FM}	Hartmann and Thuneke (1997)
Density of wood chips	0.38	t FM/m3	Hartmann and Thuneke (1997) and Spinelli (2006)
Feller-buncher costs	76.09	€/h	ÖKL (2006)
Feller-buncher harvest interruptions	25	% of $NP_{fell\text{-}bunch}$	Spinelli, Nati and Magagnotti (2006)
Front-end loader gross extraction productivity	12.6	t FM/h	Spinelli, Nati and Magagnotti (2006)
Front-end loader costs	50.2	€/h	ÖKL (2006)
Chipping gross productivity	29.1	t FM/h	Kanzian et al. (2006) and Spinelli, Nati and Magagnotti (2006)
Chipping costs (inkl. labor)	268.8	€/h	Kanzian et al. (2006)

Storage cost factors			***Source***
Wood chips storage losses	3	% of biomass per month	Mitchell, Stevens, and Watters (1999)
Whole stem storage losses	0.5	% of biomass per month	

Shipment cost factors			***Source***
Loading time	0.005	h/m^3	Hartmann and Thuneke (1997)
Loading costs	45	€/h	ÖKL (2006)
Shipment losses	2	% of biomass	
Distance to plant	10	km	
Tractor deloading	0.15	h	Kanzian et al. (2006)
Tractor speed	20	km/h	Kanzian et al. (2006)
Tractor transport capacity	36	m^3	Kanzian et al. (2006)
Tractor max. loading weight	9.4	t	
Truck deloading	0.3	h	Kanzian et al. (2006)
Truck costs	72	€/h	Kanzian et al. (2006)
Truck transport capacity	87	m^3	Kanzian et al. (2006)
Truck max. loading weight	19.5	t	Kanzian et al. (2006)
Initial time to farm	0.5	h/ha	

Recultivation cost factors			***Source***
Recult. machin. costs	46.8	€/h	ÖKL (2006)
Recult. time	6	h/ha	

Benefit factors			***Source***
Price for product	70	€/t DM	

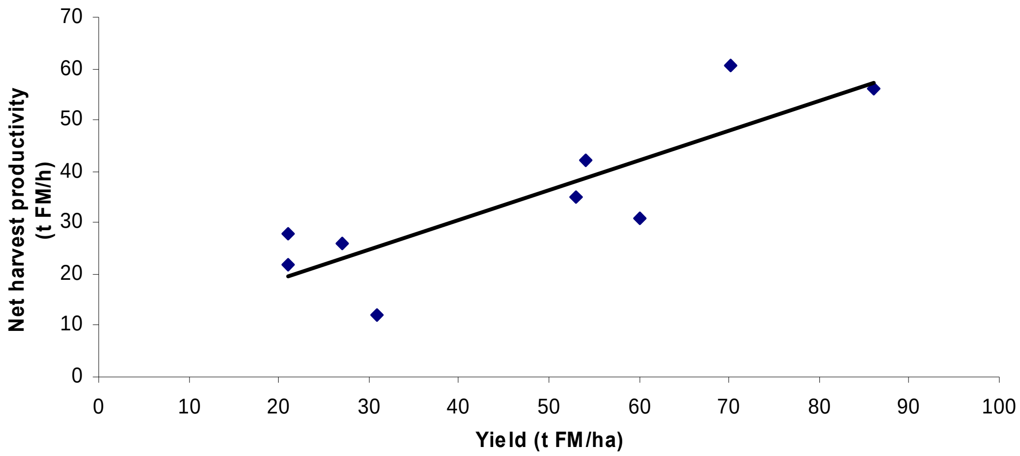
Appendix 3: Fertilizer Application for Fast Growing Trees

	Yield (t DM/ha*year)					
	6	*8*	*10*	*12*	*14*	*16*
Nitrogen (kg/ha*yr)	22	30	37	44	52	59
Phoshorus (kg/ha*yr)	4	5	6	7	8	10
Potassium (kg/ha*yr)	16	21	26	31	36	42

Source: Sächsische Landesanstalt für Landwirtschaft (2004).

In the model, the values are linearly extended for yields above 16 t DM/ha and year.

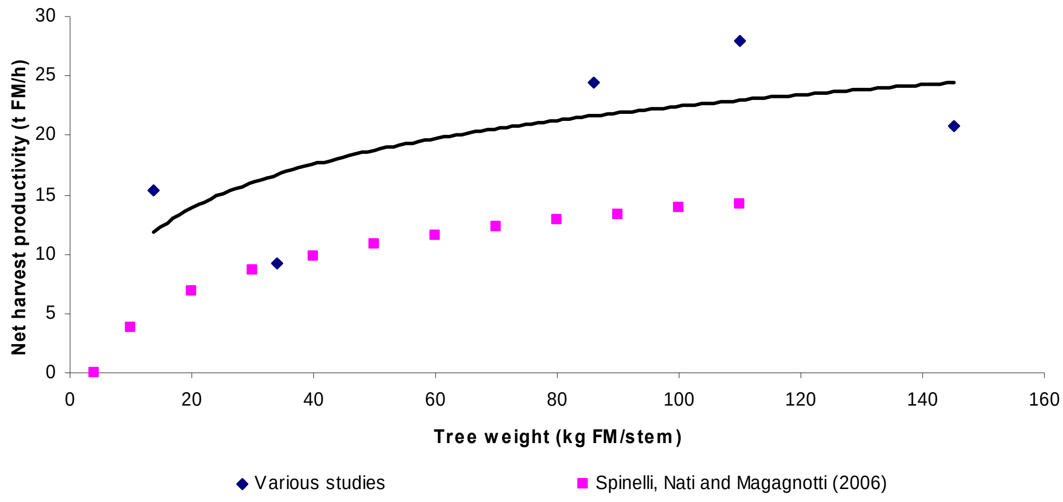
Appendix 4: Relationship of Yield and Net Harvest Productivity for Claas Jaguar



Source: Author's construction based on data from Hartmann and Thuneke (1997) and Spinelli and Kofman (1996).

Data from Hartmann and Thuneke (1997) and Spinelli and Kofman (1996) was used to estimate the relationship between biomass yields and net-harvest productivity. Only data for twin rows was used, as this is seen as the more preferable planting system with higher productivities for this harvesting machine. Spinelli and Kofman (1996) presented a range of productivity and the lowest and highest bounds for productivities and yields have been taken for the calculation.

Appendix 5: Relationship of Yield and Net Harvest Productivity for Dedicated Feller-buncher Harvester



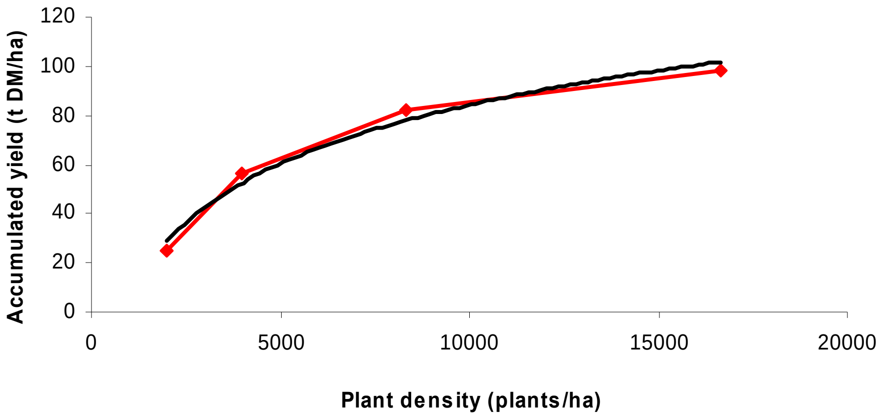
Source: Author's construction.

Spinelli *et al.* (2006a) present a function for the estimation of net harvest productivity of a feller-buncher depending on tree weights. Their results from field trials in Italy are considerably lower than those published by other authors. Burger and Sommer (2005), for example, estimated 3.96 t FM/h for a five-year rotation. Extraction and chipping is already included. This value is based on a planting density of 8,000 plants/ha and a yield of 11t DM/ha. It includes delays of 25 % of the net harvest time. One stem grew per stool and seven to eight trees had been bundled in one cycle (Burger, 2006). With the regression offered by Spinelli *et al.*, (2006a) and the above mentioned input parameter values, the gross-productivity solely for felling would be 4.2 t FM/h. This leads to a productivity of 2.8 t FM/h if extraction and chipping would be included, a value which is 30% below the one given by Burger and Sommer (2005). Another study by Spinelli *et al.* (2006b) shows even greater deviations. In order to receive more reliable results, a regression for the estimation of net harvest productivity was estimated based on the data below.

Tree weight (kg FM/stem)	14	34	86	110	145
Net harvest prod. (t FM/h)	15	9	24	28	21
Source	Burger and Sommer (2005) and Burger (2006)	Spinelli, Nati, and Magagnotti (2006)	Spinelli et al. (2006)		

Source: Author's compilation.

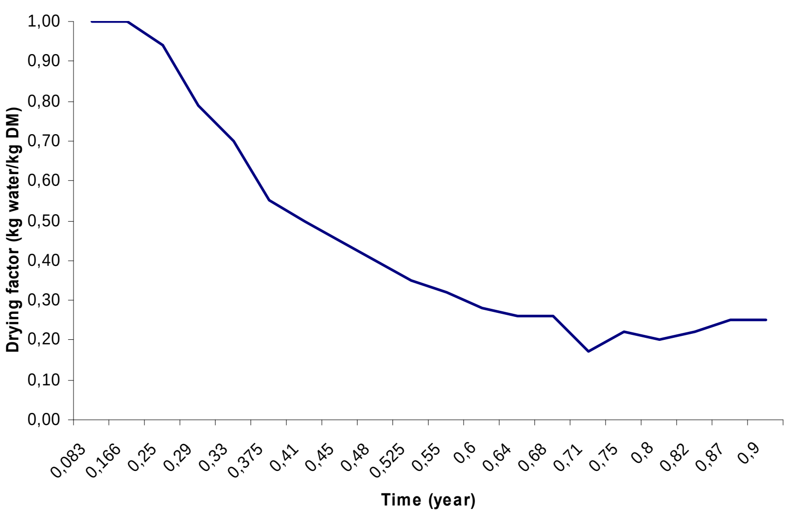
Appendix 6: Plant Density-yield Relationship of Maximum Diameter (7 cm) for Harvest



Source: Author’s construction based on Friedrich (1999).

Graphs on the breast height diameter-age and the yield-age relationship by Friedrich (1999) from a German poplar plantation planted with *Muhle-Larsen* were used for a regression on the relationship of plant density and accumulated biomass yield. This equation is used to specify the maximum rotation period until which stem diameters are below 7 cm and harvest is possible by the cut-and-chip harvester. The use of breast height diameter might overstate possible rotation periods as it is smaller than the diameter at cutting position. In reality, harvest above 7 cm might be possible in some cases, which would partially offset the former mentioned effect.

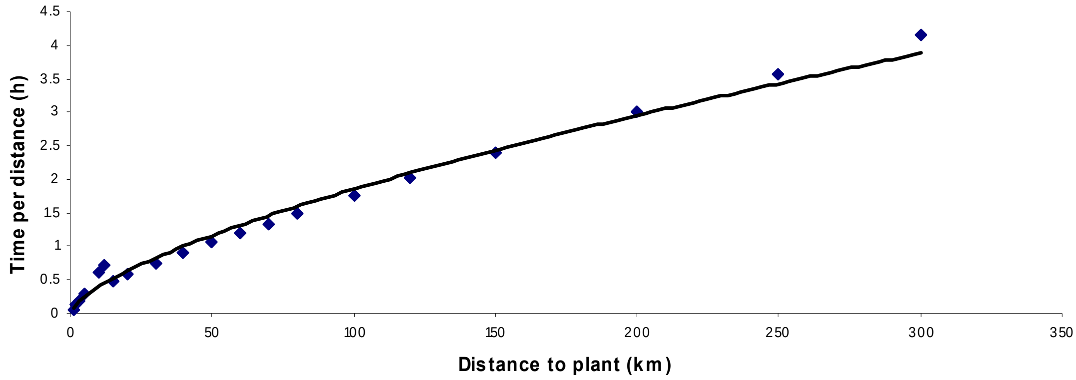
Appendix 7: Drying Effect of Whole Stem Storage



Source: Author’s construction based on Gigler *et al*. (2000).

Gigler *et al*. (2000) present drying curves for willow stems stored in piles. This data is taken to estimate drying factors, which are used to calculate the water content of wood at time of shipping.

Appendix 8: Estimation of Transportation Time by Truck



Source: Author’s construction.

Kanzian *et al*. (2006) offer two models for estimation of truck transportation time depending on the transportation distance. The model of Friedl *et al*. (2004) (cited in Kanzian *et al*. (2006)) for distances from 10 to 120 km and the model presented by the authors for distances from 4 to 12 km are used to estimate a transportation model presented in the graph above. Both cited models are based on transport of wood from forests, which might be more time consuming than transportation from agricultural sites.

Appendix 9: Nominal Production Costs for *Scenario 2 and 3 Optimal*

		Scen. 3 opt.		**Scen. 2 opt.**	
		Yrs	Costs (€/ha)	*Yrs*	Costs (€/ha)
Soil preparation	Labor	*1*	24	*1*	24
	Machinery		105		105
Planting	Labor	*1*	71	*1*	220
	Machinery		37		213
	Cuttings		313		1,800
Fence establishment	Labor	*1*	85	*1*	85
	Material		680		680
Mech. plant protection	Labor	*1,2,13, 14*	80	*1,9,17*	80
	Machinery		96		96
Fertilizer application	Labor	*13,25*	10	*9,17,25*	10
	Machinery		29		29
	Fertilizer		246		207
Management initial	Labor	*1*	300	*1*	300
Management annual	Labor	*1-25*	50	*1-25*	50
Harvest	Harvest machin.	*12,24*	1,586	*8,16,24*	1,229
	Transportation labor		1,250		44
	Transportation machin.				189
	Chipping		2,416		-
Shipment	Loading labor truck	*12,24*	219	*8,16,24*	113
	Loading machinery		307		168
	Loading labor tractor		-		-
	Transport tractor		1,658		969
	Transport truck		1,636		954
Recultivation	Labor	*25*	60	*25*	60
	Machinery		281		281