DOCTORAL (PhD) THESES

KAPOSVÁR UNIVERSITY
FACULTY OF ECONOMICS SCIENCE
INSTITUTE OF MARKETING AND MANAGEMENT
Department of Agricultural Economics and Management

Head of Doctoral School:
Prof. Dr. KEREKES SÁNDOR
Doctor of Science, Professor

Supervisor:
Dr. BORBÉLY CSABA
Associate professor

Co-supervisor:
Dr. CSIMA FERENC
Associate professor

ECONOMICAL EXAMINATION OF ENERGY PLANTATIONS AS A RENEWABLE ENERGY SOURCE IN HUNGARY

By:
POSZA BARNABÁS

KAPOSVÁR

2018

1. BACKGROUND OF THE RESEARCH, OBJECTIVES

In today's fast world, the main aim of mankind is to increase competitiveness, while disregarding our eternal dependency on the nature and the limits of the Earth's carrying capacity. As energy is the basis for the economy and production, the ecopolitical importance of renewable energy resources is unquestionable. Sustainability cannot be achieved without renewable resources, and besides that, renewables play a key role in fighting anthropogenic climate change, too.

Considering the endowments of Hungary, among renewable resources biomass has an unused potential that, if exploited, may partly replace fossil energy. This could mainly be accomplished by sustainable biomass production on low quality lands unfit for agricultural production.

The development of biomass utilization is not a definite success story. Paradoxically, several environmental concerns and uncertainties arose about their use, particularly about the production, transportation and utilization in power plants.

My research focuses on the economical and environmental sustainability of biomass as an energy source.

The aim of my research is not an exhaustive exploration of a partial problem but a synthesis of the several connected but still usually separately handled issues.

The main objects and aims of my doctoral work are the following:

1.) To explore the environmental and economical criteria of efficient production using energy plantations. Using observations of production and a model based on domestic research results I am trying to find out whether short rotation coppice (SRC) plantations can meet the requirements of either economical or environmental sustainability or both at the same time.

2.) To determine the role of cost elements in production by analyzing the cost distribution of production cycles. This can help in assessing the competitiveness of different rotations and tree species.

3.) To analyze the energetic considerations of SRC's and to make recommendations on planting and maintaining plantations.

4.) To direct attention on possible problems, difficulties and exploitable opportunities using the results from the model.

2. MATERIALS AND METHODS

The calculations examined the profitability of planting and maintaining an SRC plantation of average conditions using only own resources. Average conditions mean that the conditions of the plantation do not make any further special works necessary above the production procedures detailed. In the model the biomass is sold directly to a power plant. The financial values presented are net values.

The economical model based on the calculations is a novel approach to the topic due to the conversion and synthesis of the available knowledge. The production technology and achievable average yields that are crucial for calculating production costs and income were based on literature sources.

The competitiveness of possible technological guidelines was examined through their profitability. Biomass being a low energy density product, the effect of the varying transportation cost on the total cost at different yields were examined.

In order to determine typical yield to cost relations, four scenarios with three transportation distances were set up for each tree species (willow, poplar, black locust) by pairing cash flow variations and land conditions. Intensive and extensive production methods were determined using the extremities of production values and costs.

SRC plantations involve production periods longer than a year. Thus, economical analyses also refer to one production cycle or to a determined time period. In the financial calculations of the economical model, the accumulated results of 15 years were calculated using the different yield and cost data of scenarios, thus presenting the different payback periods and profitability of scenarios.

The effect of the time value of money on the investment was evaluated using dynamic indexes. The starting cash flow at the beginning phase of the investment and the net cash inflows of each following year were totaled using the Net Present Value (NPV) formula. The Profitability Index (PI) shows the present value of yields during the entire production period compared to the initial investment. The Internal Rate of Return (IRR) derived from the net present value reflects the internal yield of the investment.

Financial values were calculated using an expected return of 7% and zero residual value at the end of the 15 years production period. The expected return of 7% derives from the expected inflation and the profitability of alternative investments.

In addition to the cash flow analysis of the scenarios, the environmental sustainability of the production was determined using an energetic approach. The results of the economical model calculations are the basis for my conclusions that present a novel exploration of the contexts of economical and environmental sustainability.

Costs of production procedures were determined using the data of the National Agricultural Research and Innovation Centre Institute of Agricultural Engineering (NAIK-MGI). Costs were calculated as contract work, with approximately 20% profit above cost price. The database contained no data about harvest which requires special machinery, therefore harvest costs were determined using the practical experiences of experts working in this branch.

Lowest and highest production yields were calculated for all three species using literature data. Yields were expressed in the weight of absolute dry wood (oven dried tons, odt):

- Poplar 8.7-23 odt/ha/year
- Willow 10-24 odt/ha/year
- Black locust 6-20 odt/ha/year

For purchase price the contract price of the biomass power plant in Pécs, Hungary (20,000 HUF/odt) was used.

3. RESULTS

3.1. Cost distribution of SRC species

The lower growth of black locust justifies rarer harvests, thus the less income from lower yields can partly be compensated by lowering the counts of costly harvests. This is profitable as long as the harvest costs are covered by the value of the yearly growths, and as long as the growth of previous years does not decrease below the yields expected after the harvest.

The low energy density of woodchip results in high transportation costs which is further increased by its high water content. The latter is particularly problematic for poplar and willow plantations where the water content at harvest may be above 50%. Up to 20% water loss can be achieved by intermittent harvest and pre-storage which results in a 28% decrease in transportation costs per hectares. Another factor determining transportation costs is the amount of harvested biomass which was examined at 30% water content and 3 different transportation distances (20, 50 and 100 km).

The cost distribution of a production cycle of SRC plantations reflects the weight of different cost factors and production procedures. Results suggest that despite the fact that in harvest years transportation costs are determining cost elements, their weight is less when distributed to all the years of a whole production cycle, particularly with lower yields.

The differences between production costs clearly show how less costly it is to maintain an energy plantation using extensive production methods. At the 2 years cycle of poplar and willow, harvest costs have the highest share with 28% to 52%. The weight of transportation costs are 6% to 33% at 30% water content which suggests that at longer transportation distances and higher yields the share of this cost element is significant but not always determining. Land use fees amount to 16% to 30% from the total cost of the 2 years rotations.

Due to the 5 years rotation land use costs have a higher share (25% to 50%) and harvest costs have a lower share (17% to 34%) for black locust. Even though black locust plantations have a lower expected average yield but due to the longer cycle more biomass is harvested. The higher biomass amount results in higher transportation costs per hectare which can reach 43% of the total cost but only 7% to 21% at lower yields. The proportion of production costs is 7% to 20% for black locus while 9 to 28% for poplar and willow.

3.2. Protection against game damage with game fence

Due to the long production cycles, wild animals can destroy the yields of several years which may postpone return with years. The most effective protection is a game fence around the plantation. The installation cost of a game fence is at the same magnitude as the plantation costs. Besides the technical and quality characteristics of the materials used, the installation cost of the fence also depends on the land attributes, especially size and shape. As the size of the land increases, the relative cost of the fence decreases, the scale of decrease being determined by the side ratio (Figure 1).

The figure also includes the lowest (287,000 HUF/ha for black locust) and highest (659,500 HUF/ha for willow) plantation costs among the three species as well. At the highest plantation cost (willow), the installation cost of the fence decreases below 50% of the total cost at 5 hectares. At the lowest plantation cost (black locust) the cost of the fence amounts to more than twice the plantation costs per hectare. Depending on the side ratio of the land, the installation cost of the fence decreases below half of the plantation costs at 20 or 30 hectares.

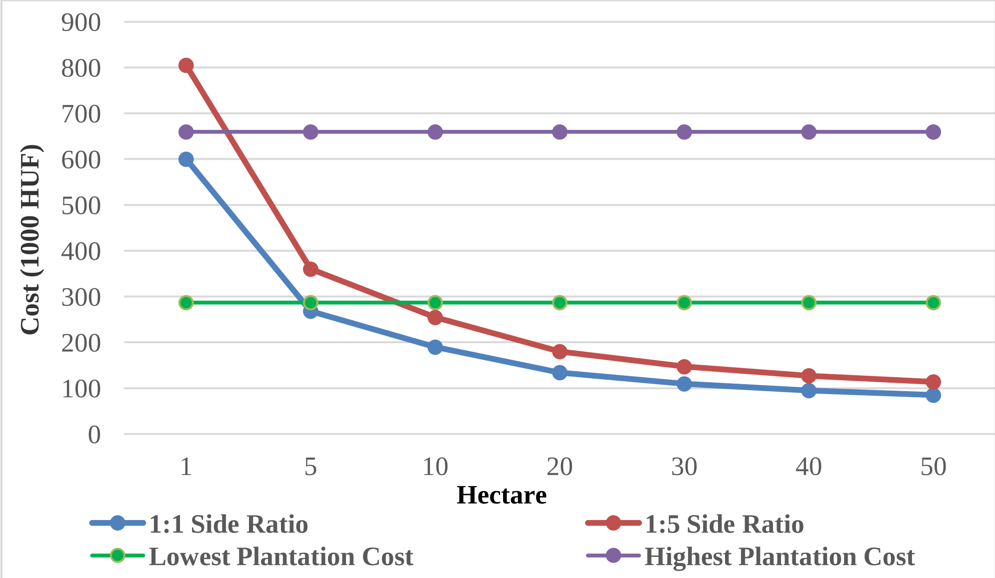

Figure 1: Relative installation cost of game fence (1,000 HUF/ha)

Source: Own calculations

Assuming that the acceptable value of the fence installation cost is below 50% of the total plantation costs, it can be concluded that the justification of the game fence depends significantly on the level of plantation costs. Fence installation costs are not included in the current model, however, I consider it important to cover this cost element as well.

3.3. Cumulative profit of the SRC species

To the four scenarios established in the model production and land characteristics can be associated with typical yield-cost relations:

Scenario 1 (S1): Production cost (low) + production value (high). With high average yields and low cost, extensive production is typical on good quality lands where outstanding outputs can be achieved with relatively low inputs.

Scenario 2 (S2): Production cost (high) + production value (low). In this scenario low yields are coupled with high inputs. This can occur on adequate quality lands with intensive production where due to unfavourable conditions (weather, game damage) lower yields were achieved in the current production cycle. Another possible reason is that the extra inputs of intensive production cannot be exploited to the expected levels. The insufficient efficiency may be a result of the production technology or unfavourable conditions on low quality lands (e.g. high water level) preventing the culture from exploiting the inputs to the desired level. This is the worst scenario.

Scenario 3 (S3): Production cost (low) + production value (low). Extensive production with low yields. This scenario is typical on low quality lands where unfavourable land conditions are not improved to a more optimal level by extra inputs.

Scenario 4 (S4): Production cost (high) + production value (high). This scenario is typical to intensive production that achieves high yields with high cost levels with a relatively high degree of reliability. This production type is most effective on good quality lands but may be successful on some lower quality lands, too.

In order to compare the four scenarios for the three species, Figure 2 shows the cumulative earnings for 15 years at all three transportation distances (20/50/100 km). The coordinates of the points are determined by the cumulative costs and revenues, with the return of the investment being shown as a red line, thus the figure reflects cost-revenue relations as well. Among the three species, black locust has both the lowest revenues and lowest costs.

The two well separable point clouds identify the economically and environmentally sustainable scenarios. The point cloud of higher cumulative earnings reflects the economically sustainable scenarios S1 and S4 with extensive and intensive production on good quality lands. The point cloud of lower cumulative earnings reflects the environmentally sustainable scenarios S2 and S3 on lands unfit for agricultural production.

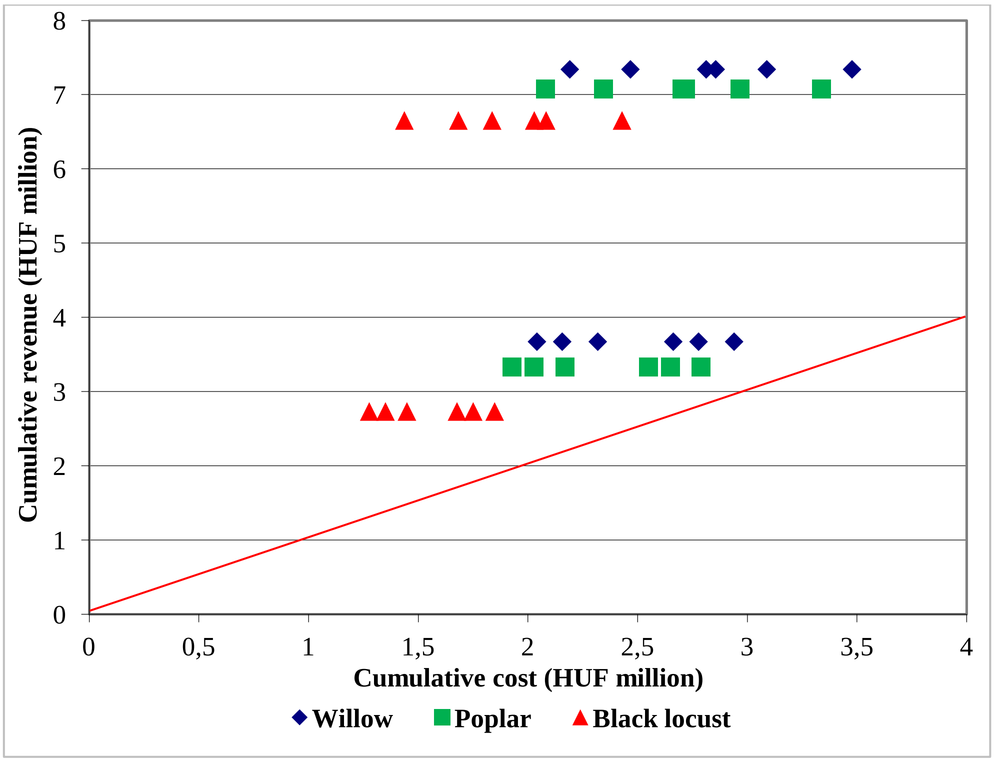

Figure 2: Cumulative earnings of poplar, willow and black SRC plantations for 15 years

Source: Own calculations

3.4. Payback periods with regard to the time value of money

Figures 3-4-5 show the discounted earnings of the three species using the present value of the expected net cash flow and the investment amounts, the sum of these reflecting the net present value of the investment. The intersections of the curves with axis X show the discounted payback period for each scenario at 7% discount rate.

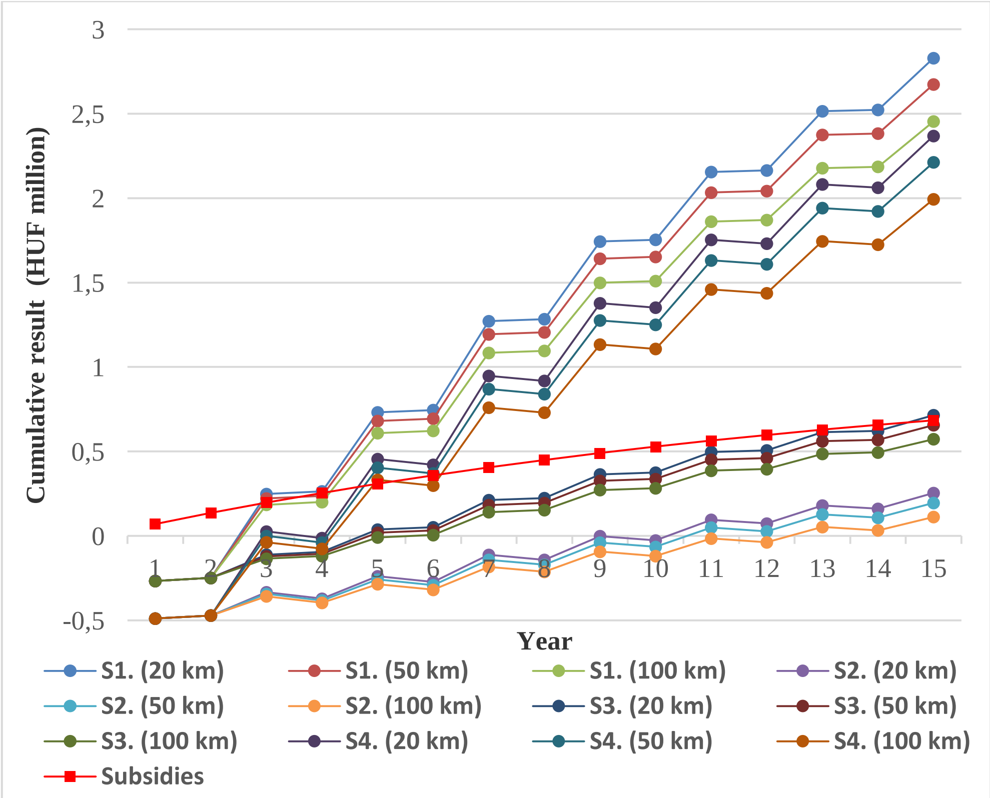

Figure 3: Discounted cumulative earnings of a poplar SRC plantation for 15 years

Source: Own calculations

Scenario S1 with 20 km transportation distance and scenario S2 with 100 km transportation distance are the extremes for all three species, with the net present value of the rest of the scenarios and transportation distances spreading between them.

In high yield scenarios S1 and S4, discounting inflicts no significant change in payback periods, which reduces financial risk. In the 15th year the discounted values in high yield scenarios are around the half, while in low yield scenarios less than the half of the nominal value.

From dynamic profitability metrics it can be deducted that transportation distance does not significantly influence return time in any scenarios or species. According to the results of Internal Rate of Return (IRR) and Profitability Index (PI), scenario S1 is the economically most favourable one. Due to the higher plantation costs, metrics of willow are lower that of poplar. In spite of its lowest Net Present Value (NPV), black locust has the highest PI, which can be attributed to the low investment costs.

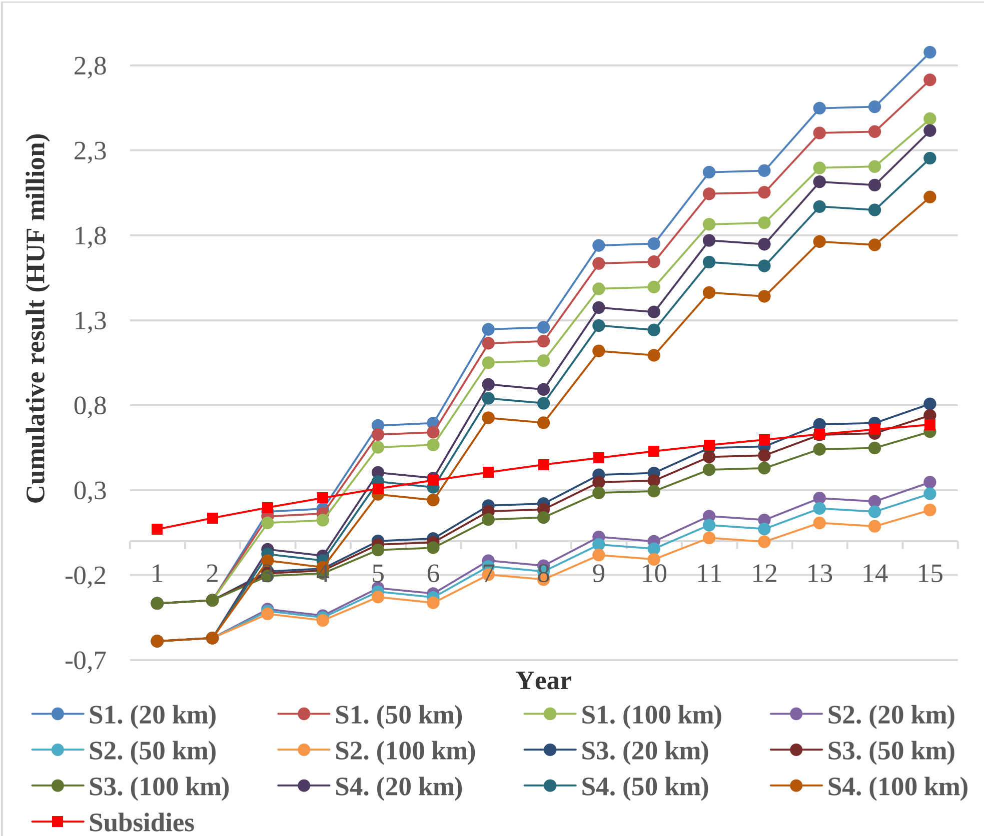

Figure 4: Discounted cumulative earnings of a willow SRC plantation for 15 years

Source: Own calculations

The condition of 7 years' discounted return period is achieved in three scenarios for all three species: S1 (extensive farming on good quality lands), S3 (extensive farming on low quality lands) and S4 (intensive farming on good quality lands). In scenario S3, in spite of the relatively fast return, NPV in the 15th year is less than 750,000 HUF for all three species (poplar: 656.528 HUF, willow: 739,673 HUF, black locust: 684,777 HUF).

In all three figures, the NPV of area payments are shown with a red line, which value is 685,106 HUF in the 15th year. Farmers are entitled to area payments without planting SRC's. Therefore, only those scenarios can be accepted as economically sustainable on the long term whose values are above the area payments. In this case, these are scenarios S1 (extensive farming on good quality lands) and S4 (intensive farming on good quality lands).

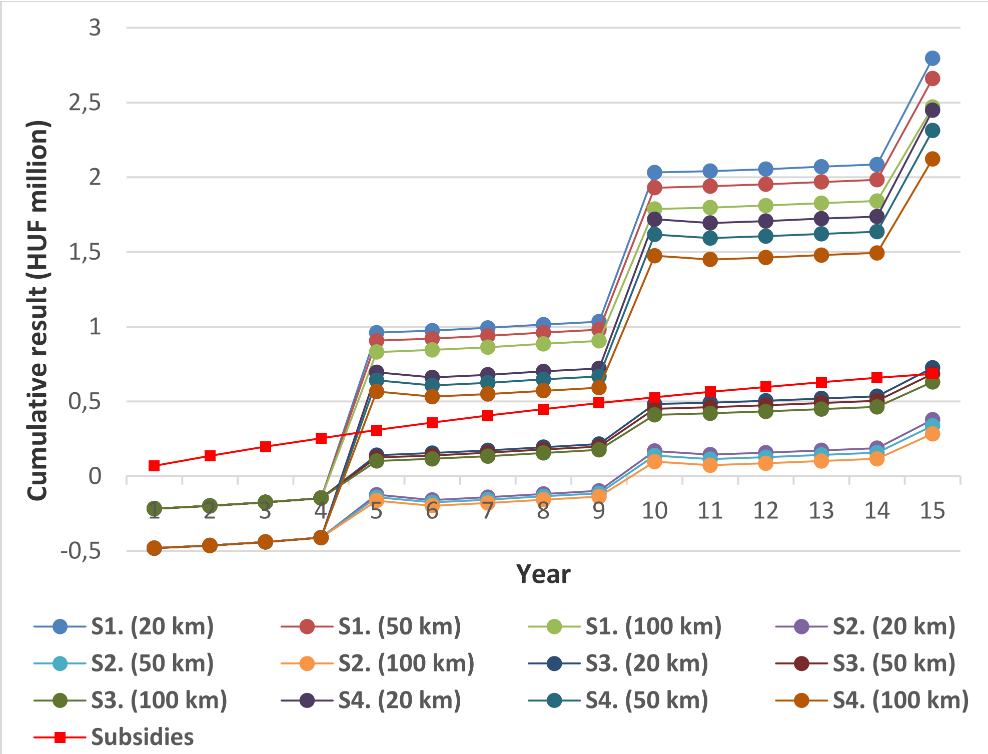

Figure 5: Discounted cumulative earnings of a black locust SRC plantation for 15 years

Source: Own calculations

For black locust (Figure 5), the 5-year rotation and the different production technology may counteract the disadvantage resulting from the lower growth. Thus, although on different lands, black locust plantations can be as successfully utilized as the other two species. The longer rotation, however, results in higher unpredictability of production and financial risks, too. Financial assets are committed for a longer time, and plantation costs can only be returned in every 5th year.

Intensive farming is the most effective way to achieve an earlier return and to minimalize risks. Even though the biomass yield of SRC plantations is higher than that of traditional forests, it does not mean that SRC's can be sustainably maintained on lands of any quality. Due to their ecological requirements, not all lands unfit for agricultural production are suitable for SRC plantations.

3.5. Energy balance of SRC's and doubts about the results

Energy plantations for producing primer biomass are a result of the efforts to increase the use of renewable energy resources. Thus it is necessary to examine the factors influencing sustainability, especially the energy balance. One of these factors is the difference of the energy produced and the energy used for production and utilization; the other factor being the ratio of energy output and input.

The exact energy input is questionable, especially in intensive production, due to the difficulties in calculating the energy used for the manufacture and transportation of fertilizers and pesticides.

Due to the fluctuating yields, the produced energy varies in a wide range. Uncertainty is further increased by the high fluctuations in the water content of woodchip which influences caloric value. In the literature there are significant differences in the caloric values used for energetic calculations. The significant differences (18% and 47%) between the two caloric values used in the current model and the extremes of yield add up, thus increasing the differences. Table 1 shows the differences between caloric values at 30%

and 50% water content. Due to the fact that all factors used for the calculation vary in a wide range, no exact ratios can be determined for the energy balance, only the correlations can be examined. The yield fluctuations and the differences between caloric values are determining factors in judging the energy ratio from the point of view of environmental sustainability.

Table 1

Caloric values of SRC's at 30 and 50% water content

Species	Caloric value at 30% water content (GJ/ha/year)		Caloric value at 50% water content (GJ/ha/year)	
	Unit values		Unit values	
	Lowest: 12,2 MJ/kg	Highest: 14,44 MJ/kg	Lowest: 7,1 MJ/kg	Highest: 10,44 MJ/kg
Poplar	151,3	473,6	123,5	480,2
Willow	173,2	493,9	142,0	501,1
Black locust	103,7	411,5	85,2	417,6

Source: Own calculations

This fact makes the long term environmental sustainability of biomass production and use questionable. Energy ratio is much more suitable to reflect the production efficiency on the examined plantation using the energy output per energy input.

The energetic metrics (difference and ratio of energy output and input) can be estimated in specific cases but no general conclusions can be drawn for the energy production of SRC primer biomass sector as a whole.

The water content of woodchip affects not only caloric value but transportation costs and carbon dioxide emission as well. Thus it is not sufficient to determine the energy balance/energy ratio of the production but the energetic and technological examination of the whole SRC sector is necessary. The good energy balance of the production may be degraded by the transportation and utilization of high water content woodchip, and besides that, the efficiency level is also fundamentally determined by the method of final utilization.

For electricity-only utilization in power plants used in the model, the conversion efficiency is between 22% and 35%. From the point of view of electricity generation this efficiency means that only one third-one quarter of the energy content of the biomass is utilized. From the point of view of the energy ration of SRC plantation this efficiency means that at least a fourfold energy output is necessary to produce the same amount of (electrical) energy as the fossil energy input used for the production and manipulation of the biomass.

This suggests that the environmentally more sustainable (lower energy ratio) extensive production is questionable on low quality lands where the plantation of SRC's are encouraged by many.

As a counter-argument it can be mentioned that the efficiency of fossil power plants in Hungary is 20% to 75%, depending on the energy source, capacity and technology. Thus, only this proportion of the fossil energy used for biomass production could be transformed into electric energy. Besides that, efficiency improvement by modernizing existing fossil power plants may also be an alternative to building new biomass power plants.

In general it can be concluded that when studying the energy balance of biomass produced for electricity, the electric energy amount produced by the conversion should not be related to the energy content of the biomass but instead, to the total input energy used for the production and manipulation of the biomass.

From the point of view of environmental sustainability it must be emphasized that among the purchase criteria of power plants there are no regulations about environmental sustainability and harmful emissions. Transportation being not the responsibility of the power plant, the energy balance degradation and excess carbon dioxide emission derived from transportation is difficult to control.

4. CONCLUSIONS AND SUGGESTIONS

The production technology of short rotation coppice (SRC) is an attempt to make a normally extensive sylviculture work in an intensive production system while meeting the requirements of economical and environmental sustainability at the same time. SRC attempts to satisfy an ever increasing, almost infinite electricity requirement by a system with land and biological limits. The unpredictability is further increased by the fact that meeting a physical demand like the electricity requirement by biological systems presents a risk of exposure to abiotic and biotic factors as well.

Since the majority of publications on this topic do not focus on the whole issue but on partial tasks or problems, and the general basic data used for the calculations are not always consistent, I recommend creating a standard comparison system with the corresponding aspects in order to facilitate the interpretation of research data.

The relatively high investment costs and the intensive production technology result in a pressure for high output in order to shorten return time and to keep risk factors at the minimum. One of the two directions aims at higher output by exploiting maximum growth potential using shorter rotation periods. In this case rotation periods are determined by the proportion of yearly yield compared to the actual average yield. The other direction prefers longer rotation periods due to the high costs of harvest. The difference between these two directions is reflected in the analysis of economical models of willow and poplar SRC's with short rotation periods and higher growth potential versus black locust SRC's with 5 years rotation periods and lower growth potential. Longer rotation can compensate for the lower yearly yield of the coppice.

The difference between intensive and extensive production is significant from both economical and environmental points of view. Farmers are generally interested in intensive production in order to achive high and balanced yields while exploiting maximum growth potentials. SRC's are recommended for lands unfit for agricultural production, however, on these lands the extra input of intensive production, the biological potential of special breeds cannot be efficiently exploited due to land conditions. On these lands extensive farming should be considered using specially selected breeds. In the literature a wide range of yield figures can be found but efficient production can only be achieved at the highest yield values. Lower yields can be compensated by cost optimization for a limited time but the cumulative outputs of the model show that profit can only be generated with high yields. So, farmers should strain after yield maximization which can be achieved either by intensive production or on better lands even by extensive farming, too. For environmental sustainability the highest possible energy ratio should be desirable which can be achieved on good lands and by extensive farming. Good quality lands can be excluded from the scenarios for favourable environmental sustainability as SRC's are justified only on lands unfit for agricultural production. As shown above, intensive farming is not always economically sustainable on low quality lands, and due to the extra input its energy ratio is also lower than the desired level for environmental sustainability. In intensive production, the yield increase from extra input reduces the energy ratio. As a result, return will be uncertain and the extra input will not be profitable from an energetical point of view. On low quality lands, extensive production can be environmentally sustainable but the probable low yields make it economically unsustainable. From the established model it can be concluded that SRC's can meet the requirement of either economical or environmental sustainability but not both at the same time. Although extra inputs (may) result in higher yields but the energy ratio will still decrease.

Differences between production cycles, uncertainties and weather exposure make analysis and model making difficult. Due to the 15 to 25 years life expectancy of plantations, climate change is another risk factor, especially for poplar and willow due to their high water requirement. This uncertainty can also negatively affect the farmers' investment mood for SRC's. Based on the average yields and other data used for the calculations, practically any theory about SRC's can be either verified or refuted.

In order to ensure predictable production, plantations should be protected with a game fence. The installation cost of the fence cost depends on the size, shape and exposure of the land. As the size of the land increases, the relative cost of the fence decreases significantly. Within the financial circumstances of my model, a game fence is justified above 5 or even 20-30 hectares. In my opinion, a general rule cannot be set up in this matter.

The products of SRC's are at a competitive disadvantage against biomass byproducts. Biomass main products are results of investments lasting for several years, therefore they are more vulnerable to changes in purchase and utilization trends and to the status of substitutive byproducts. Thanks to the subsidized purchase system, electricity from primer biomass is currently purchased at a price above the market price. Changes in the subsidy system and in the electricity purchase prices affect biomass purchase prices as well.

The economical and environmental efficiency of primer biomass production is often compared to those of other agricultural plants in the literature. Based on the assumption that biomass production is justified only on lands unfit for agricultural production, it does not compete with agriculture in land use, so in my opinion this comparison can only yield theoretical benefits. Traditional forestry and industrial roundwood production are the real competitors of SRC's.

The profit conditions of SRC's should be reviewed based on the available grant resources and current yield figures. If justified, SRC's may be turned into medium rotation industrial roundwood production or traditional forestry, or may be replanted in accordance with forestry regulations. However, the input costs of these procedures should be taken into consideration, too.

The use of biomass is an often reasoned with the statement that burning biomass is carbon dioxide neutral, for only as much carbon dioxide is produced during burning as much the plants absorbed during their lifetime. In my opinion this is only partially true as producing and manipulating biomass is done using fossil fuels. Thanks to biological productivity the input energy is multiplied, from which some can be used during utilization. In my opinion, this would be the correct statement: the utilizable energy during biomass burning should be more than the fossil energy used for the production and manipulation of biomass products. Biomass being a conditionally renewable resource, fossil energy must be used every year for biomass production. As a conditionally renewable resource, the return of the yearly inputs poses both financial and energetical risks due to the unpredictable production. This presents a competitive disadvantage against traditional renewable resources.

The conversion efficiency of biomass based electricity generation is not expected to improve in the near future as opposed to solar and wind energy production, which are based on physical not biological grounds and they need no lands for the production. This may result in conditionally renewable resources, including primer biomass production being sidelined on the long term. As opposed to the high material cost of biomass based electricity generation, solar and wind energy production has a high initial investment requirement but low yearly maintenance cost. With biomass production, first-cost depends on the variable yield, and besides that, production costs depend on the price of fossil fuels which make this branch difficult to plan from both economical and environmental points of view.

For grants and investments for renewable resources not only the economical but also environmental sustainability should be examined including constant traceability for the whole product line. Currently only the emission of power plants is controlled but the production and transportation of biomass are not.

The European Union has always made great efforts to unify and liberalize its internal energy market. The market unification and the connection of European networks present the possibility to move production capacities to the most optimal member states, after taking comparative and competitive factors into consideration. Power plants with high costs may be replaced by more competitive plants in other member states. Competitiveness can result from the availability of cheaper energy sources, a more developed technology or a more beneficial investment environment. This applies to both fossil and renewable resources. Therefore I recommend that member states that are able and willing to invest into the energy branch including renewable resources on a large scale and in a sustainable way should be allowed and even encouraged to do so. I also recommend to establish a trading system of renewable resources including the possibility of allocation, in a similar way to carbon dioxide emission trading. This may prevent member states from making forced and sometimes environmentally less reasoned investments in order to meet their obligations.

5. NEW SCIENTIFIC RESULTS

1. My new results refute the professional opinion that short rotation coppice can effectively be cultivated on all low quality lands.
2. My calculations clearly prove that willow, poplar and black locust plantations can only be grown profitably on the long term by using intensive farming methods and/or on good quality lands.
3. The results from the research on energy balance show that SRC's can meet the requirements of either economical or environmental sustainability but the two criteria cannot be achieved at the same time.
4. It can be concluded that due to their low conversion efficiency and the unpredictability of production, electricity generation based on conditionally renewable SRC biomass cannot compete with traditional renewable resources in Hungary on the long term.

6. PUBLICATIONS IN THE TOPICS OF THE DISSERTATION

Journal Articles in Hungarian

1. Posza B., Borbély Cs. (2015): Trendek és a megújuló energiaforrások felhasználásában. Acta Scientiarum Socialium 44 sz. pp. 81-92.
2. Posza B., Borbély Cs. (2017): Fás szárú, sarjaztatásos energetikai ültetvények gazdasági-környezeti modellje. Gazdálkodás 61. évf. 4. sz. pp. 310-321.
3. Borbély Cs., Posza B. (2018): Az energiatermelés és -felhasználás jövőképe, különös tekintettel az elektromos autók elterjedésére. Követ Egyesület a Fenntartható Gazdálkodásért 23. évf. 1. sz. pp. 11-12.
4. Posza B., Borbély Cs. (2018): A fás szárú energetikai ültetvények szerepének vizsgálata az energiaellátásban. Tér – Gazdaság – Ember 6. évf. 2. sz. (in press)

Journal Articles in Foreign Languages

1. Posza B., Borbély Cs. (2016): Conceptions on sustainable energy. Regional and Business Studies 8. évf. 1. sz. pp. 1-14.
2. Posza B., Borbély Cs. (2018): Sustainability examination of the short rotation coppices. Acta Agronomica Óváriensis 59. évf. 1. sz. (in press)

Full Text Conference Papers

1. Borbély Cs., Posza B. (2016): Fenntartható élelmiszer fogyasztás egy pazarló világban. XV. Nemzetközi Tudományos Napok „Innovációs kihívások és lehetőségek 2014-2020 között", Károly Róbert Főiskola, Gyöngyös, 2016. március 30-31.