Original Paper

Production function estimation and economics of fast-growing plants cultivation for bioenergy purposes. Case study of Kolíňany

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ABSTRACT

The paper explores the economic opportunities of growing fast-growing plants for bioenergy production and use. Based on primary data of the above-ground dry biomass of the *Miscanthus × giganteus*, from the experimental field of Kolíňany, the average yield during the life cycle of the crop was 33.31 t · ha^{-1} (stand. dev. 7.07). The next step was assembling the economic model of gross financial yield based on using the biomass for the production of bioenergy. Using the Discounted Cash-flow model, the gross financial yield, neglecting the costs, was set to 1547 € · ha^{-1}. Finally, adjusting for the growing conditions of the Miscanthus, we set the gross financial yield as a deferred annuity to 3036.93 € · ha^{-1} per one life cycle of the crop.

KEYWORDS: dry ground biomass, perpetuity, *Miscanthus Giganteus*, Gompertz curve, discounted cash-flow model, deferred annuity

JEL CLASSIFICATION: C13, C51

INTRODUCTION

The paper focuses on the economic analysis of the possibilities of using dry biomass of fast-growing trees for bioenergy purposes. Biomass, as a potential source of energy, is ranked among the so-called "alternative energy sources." This term refers to forms of energy that are outside the conventional forms of energy. It can cover both renewable and non-renewable energy sources. The importance of alternative energies has come to the forefront in the context of oil shocks in the 1970s that hit the global economy and contributed to a surge in fossil fuel prices [1]. According to the IEA, currently, around 24% of energy demand is met by renewable energy sources. Their importance is expected to continue to grow and to meet up to 30% of global energy demand in 2023. Hydro energy remains the most critical resource in meeting global energy demand, at 16%, followed by wind (6%), solar (4%) and bioenergy (3%) [2].

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Renewable energy sources (RES) as alternative fuels offer some advantages. The most important reasons for promoting the development of RES [3]:

a) Contributing to the reduction of CO_2 emissions and mitigating the effects of climate change. The concentration of greenhouse gas emissions (GHG) in the air is increasing mainly due to the energy dependence of developed countries on fossil fuels. There are strong assumptions that rising greenhouse gas emissions will lead to the warming of the planet. Renewables are largely low-carbon or neutral, and increasing their levels of use can contribute to a decline in GHG concentrations over the long term.

b) Energy security. Energy security has once again become a concern for the depletion of available fossil fuel deposits at world level and the decline in production levels in England and the US; the growth of competitiveness and energy demand of third-country economies and the political instability of hydrocarbon-rich areas.

c) Increasing energy availability. It is currently estimated that at least 2 billion people do not have access to clean energy sources. The problem is even hotter in rural areas of developing countries. RES offers some benefits in this regard they reduce environmental and health damage and improves working conditions.

d) Employment opportunities. The use of RES has the potential to create jobs and increase employment thanks to a decentralized, modular technology structure.

e) Other spill-over effects. The use of RES contributes to improving macroeconomic stability by reducing dependence on hydrocarbon fuel imports and improving the current account of the country's balance of payments in international trade.

However, in spite of the clear advantages of using renewable energy sources mentioned above, these energies have currently not been able to compete against traditional energy sources such as hydrocarbon fuels and other sources. The literature has identified a number of barriers to the more intensive penetration of RES into the energy markets. Painuly [4] provided a framework for identifying and analyzing barriers. In general, these barriers can be analyzed at several levels: they can first be included in a broader category. Within each category, a certain number of barriers can be identified. At the third level, conditioning factors can be identified [4].

There are four main categories of barriers with factors within these categories. These include technology barriers (related to supply), unequal market conditions (compared to the fossil fuel market, market barriers (such as network access, regulatory measures), and non-market barriers (such as administrative measures and others [5].

In practice, the economy of RES production faces several problems. The most serious ones may include [1]:

(a) Inappropriate valuation methods. The value of electricity for end consumers varies according to the mode of use (low tariff vs. high tariff). However, the supply of energy from RES is indivisible, which causes complications in valuation with an impact on the viability of RES projects.

(b) Non-internalizing externalities. RES has some environmental advantages over fossil fuels. However, the production and use of fossil resources often bear "social" costs that reduce the social surplus and are not fully reflected in the price. On the other hand, RES are at a disadvantage.

The most important costs of RES production can be included [1]:

(a) Energy costs. These costs are generally related to the production of energy in energy installations: energy, operating, and maintenance costs.

(b) Capacity costs. These costs include installation costs and fixed operating and maintenance costs. For RES, they often represent the main cost element, often up to 50% - 80% of the total cost.

(c) Other costs. These other costs can often include a broad category of costs, depending on the nature of the renewable resource. In general, e.g., environmental costs related to adverse environmental and climate impacts, reserve capacity costs, cultivation and establishment costs, and others.

MATERIAL AND METHODS

The main sources of the research are primary sources of data on hectare crops of selected species and their varieties of fast-growing tree species (FGT), which were established at the experimental centre of biomass cultivation in Kolíňany. The object of investigation was the selected variety of Miscanthus: Miscanthus Tatai. For the given variety, experimentally measured annual yields of the yield of dry above-ground biomass directly usable for bioenergy production were obtained. In the first step of the investigation, we estimated the average yield of the dry above-ground biomass using the mathematical function within the life cycle of FGT. After several experiments, based on empirical and theoretical sources and knowledge, we chose the Gompertz function to estimate and extrapolate dry biomass yield values, which can be written as follows:

$$y_t = \beta_0 e^{-\beta_1 e^{-\beta_2 t}}, \qquad (1.0)$$

where e represents the basis of the natural logarithm, β_0, β_1 a β_2 represent estimates of model parameters and t represents time trend $t_i = 1, 2, \dots t_n$ [8].

After determining the parameters of the chosen mathematical model, we were able to determine the average height of dry above-ground biomass for variety within of investigated species. In the next part of the study, we continued with the Miscanthus Tatai species, because of the availability of data on biogas content after biomass gasification and its calorific value as an energetic parameter. The experimentally determined data were converted to a unit of energy consumption measured in kWh, and the unit price for kWh consumption for the end consumers of electricity from the energy supplier in Slovakia was determined. On the basis of the above data, it was possible to construct a relatively simple economic model of the present value of bioenergy from FGT grown for experimental purposes in the experimental field in Kolíňany. In general, we identified the first potential income considering the relatively infinite cultivation time of the investigated FGT as perpetuity.

$$PV = \frac{CF_t}{r}, \qquad (1.1)$$

where CF_t represents cash-flow received in time $t_i = 1, 2, \dots t_n$, r represents the chosen discount rate. Respecting the life cycle of the individual SRC as well as the crop cycle, we used the standard discounted cash-flow model (DCF) and the delayed annuity maturity model for further estimates of Present Value.

$$PV = \frac{CF_1}{(1+r)} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_n}{(1+r)^n} \qquad (1.2)$$

$$A = P \cdot \frac{[1 - (1 + r)^{-n}]}{(1 + r)^{t \cdot r}}$$

$$(1.3)$$

where *A* represents the annuity, *P* is the payment, *n* is the number of periods, and *t* is the number of deferred periods. The discount rate r represents the required rate of return and, in general, can be written as

$$r = r_f + r_m \,,$$

$$(1.4)$$

where r_f is the risk-free interest rate and r_m is the risk premium.

RESULTS AND DISCUSSION

In the first step of the study, we made individual estimates of the yield of dry above-ground biomass of selected species of Miscanthus considering the twenty-one-year life cycle.
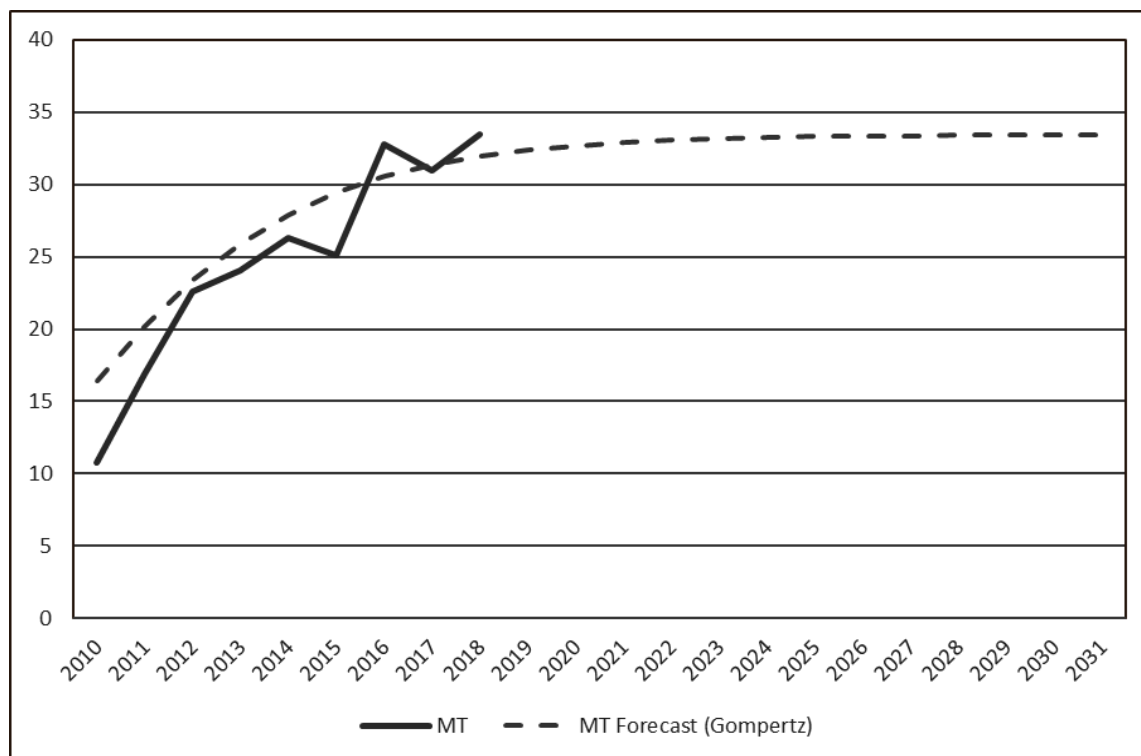

Fig. 1 Average dry above-ground biomass of *Miscanthus Tatai*, extrapolation of the trend
Source: own calculations

Tab. 1 Historical yields of dry above-ground biomass of *Miscanthus Tatai* $[t \cdot ha^{-1}]$ using Gompertz curve

Variety/year	2010	2011	2012	2013	2014	2015	2016	2017	2018
MT	10.8	16.9	22.6	24.1	26.3	25.1	32.82	30.94	33.45

Source: primary data, Kolíňany 2019

Tab. 2 Prognosis of the trend of the yield of dry above-ground biomass of Miscanthus Tatai $[t \cdot ha^{-1}]$ using Gompertz curve

Prognosis: Gompertz curve extrapolation	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
	32.4	32.7	32.9	33.1	33.2	33.3	33.3	33.4	33.4	33.4	33.4	33.4	33.4

Source: own calculations

The average yield of the dry above-ground biomass was estimated at $30.23 \ t \cdot ha^{-1}$, with the standard deviation of the estimate (SD) being 4.72. The confidence interval of the estimate was set at [28.26; 32.5] at the significance level $\alpha = 0.05$.

In the next part of the study, we will derive an economic model of biomass profit for bioenergy purposes. Gasification in the biogas plant was chosen as the primary technology for obtaining bioenergy. A useful component of this process is precisely biogas, which is then converted into another type of energy (such as electricity, heat). Biogas yield of the grass feed is about $140 \ [m^3 \cdot t^{-1}]$ [6], while the experimentally determined value at the biogas station at the Slovak University of Agriculture in Kolíňany was $113 \ m^3.t^{-1}$. In terms of combustion parameters of gases, in the case of biogas, the net calorific value is $6 \ kWh.m^{-3}$ [6]. On average, the price of 1 kWh for the end consumer, taking into account the electricity used for cooking, lighting, and heating in combined modes (NT - low tariff and VT - high tariff) was empirically determined at € 0.0685 including VAT.

Based on input data on the average dry biomass yield (Miscanthus) and biogas calorific value, and the unit price of kWh, we were able to determine the cash flow from 1 ha/year at € 1547. Furthermore, we have determined the potential gross yield assuming infinite perpetuity at a level, considering a discount rate of 10%:

$$GI = \frac{CF}{r} = \frac{1547}{0.1} = 15470 € \cdot ha^{-1}.$$

In the next step, we determined the life cycle of the Miscanthus stand, the maturity, and the harvest cycle period. The determination of these parameters was based on experimentally determined life cycle data – 21 years, grain maturation – 2 to 4 years and collection cycle period – 3 years [7]. Thus, 7 crops can be expected during the plant life cycle. Thus, using the DCF model, we determined the Current Value of Financial Return in the 3rd year of the collection cycle as follows:

$$PVGI_3 = \frac{CF}{(1+r)^3} = 1162.28 € \cdot ha^{-1}].$$

Then we determined the present value of the total gross financial income, consisting of 7 collections over the entire life cycle of the crop, by estimating an annuity with deferred maturity, abstracting the costs of cultivation and energy conversion.

$$PVGI = \sum_{n=1}^{7} \frac{CF}{\{a_n\}^7} = 3036.93 € \cdot ha^{-1},$$

where $a_n = (1+r)^{3n}$.

CONCLUSIONS

The main aim of the article was to point out the possibilities of FGT cultivation for the production and obtaining bioenergy. The aim of the paper was to derive a financial model of the profit generated by the sale of energy produced to end customers, abstracting the costs of cultivation and conversion to energy. The amount of gross financial income was determined on the basis of data from the primary collection (experimental area Kolíňany) and the secondary data from theoretical and empirical sources (volume of biogas in a tone of dry biomass, the calorific value of biogas and price relations of electricity). The financial model was developed, taking into account the real investment-business conditions when deciding on the allocation of investment. The amount of gross financial income was determined for the species *Miscanthus*, variety *Tatai*, on the basis of the mass of dry above-ground biomass in $t \cdot ha^{-1}$ with extrapolation of the production curve over the entire life cycle of the crop. The value parameters of the model can be made more realistic by clearing the revenue from the costs of growing, converting, and supplying energy to the network for end customers, including any subsidies to promote the use of RES, managing FGP cultivation to ensure annual crop harvesting, etc.

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