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Economic assessment of the integrated generation of solid fuel and biogas from biomass (IFBB) in comparison to different energy recovery, animal-based and non-refining management systems

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HIGHLIGHTS

- ▶ Economic assessment of energy recovery from semi-natural grasslands.
- ▶ Energy recovery systems make profitable use of semi-natural grasslands.
- ▶ Animal-based systems rely on optimal framework conditions, otherwise not profitable.
- ▶ Mulching and composting systems are loss-making options of grassland preservation.
- ▶ Selected energy recovery systems can buffer changing environments best.

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ABSTRACT

The study aimed at the identification of favourable land use options for semi-natural grassland management and preservation. Economic assessments of energy recovery by the integrated generation of solid fuel and biogas from biomass (IFBB) in comparison with dry fermentation (DF) and hay combustion systems (HC), beef cattle production (BC) and non-refining landscape preservation measures, such as mulching (MU) and composting (CO), were carried out in this study. Energy recovery systems made profitable use of semi-natural grasslands with the highest economic returns attained by IFBB-AO (Return On Investment, ROI: 22.75%) and HC (ROI: 22.00%) systems, followed by the IFBB-SA (ROI: 7.71%) and the DF system (ROI: 6.22%). Animal husbandry (BC) and non-refining management systems (MU, CO) were not profitable considering the current framework conditions. Input parameters critical for profitability were modified in order to identify influences of changing framework conditions.

1. Introduction

The high nature value of semi-natural grasslands has been maintained by extensive agricultural utilisation for centuries (Eriksson et al., 2002) and will further depend on extensive management in the future to avoid biodiversity decline (Paracchini et al., 2008). The preservation of rare flora and fauna in established open agricultural landscapes not only conserves biodiversity but also provides external benefits by enhancing recreational value and tourism, therefore strengthening the micro- and macroeconomic development of regions (Pruckner, 1995). However, with up to 80% lower harvest yields compared to intensively managed grasslands and poor feed quality (Isselstein et al., 2005) the use of semi-natural grasslands for animal feeding becomes economically inefficient. In addition, the shift towards an intensification of grasslands or using concentrates grown on arable land to meet the requirements of increasing animal performances has lead to a rising abandonment of bio-diversity rich grasslands (Rösch et al., 2009).

On a European scale, great efforts have been made to maintain high-value vegetations. EU spendings for environment measures, including the preservation of semi-natural grassland habitats, account for nearly 20 billion € between the years 2007 and 2013,

Abbreviations: b, y axis intercept (gradient); BC, beef cattle; CH_4, methane; CHP, Combined Heat and Power plant; CO, composting; CV, critical value; d, day; DF, dry fermentation; DM, dry matter; € ct, Euro cent; FCF, Free Cash Flow; ha, hectare; HC, hay combustion; IFBB, integrated generation of solid fuel and biogas from biomass; IFBB-AO, IFBB-add-on system; IFBB-SA, IFBB-stand-alone system; IRR, Internal Rate of Return; LHV, lower heating value; lN, normalised litres; MU, mulching; MWth, Mega-Watt thermal performance; oM, organic matter; ROE, Return On Equity; ROI, Return On Investment; t, ton; yr, year.

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not regarding co-financing of the member states (EC, 2011). The implemented agri-environmental schemes, however, cannot always fully contribute to halting the decline of semi-natural grassland habitats (Strijker, 2005). Therefore ecologically valuable and economically sustainable management options for semi-natural grassland communities are desired.

As the demand for the provision of renewable energy resources increases in the context of future fossil fuel shortages the use of biomass for energy generation has rapidly grown, often linked to negative effects regarding biodiversity, soil health or nitrate leaching (Graß and Scheffer, 2005). Therefore, an energetic use of semi-natural grassland material grown on poor soils or areas less favourable for agricultural production could be another management option, that neither competes with food production nor causes ecosystem destruction (Tilman et al., 2006). Global potentials for the production of biomasses from semi-natural grasslands have roughly been estimated e.g., by Field et al. (2008) and Tilman et al. (2006) to account for 386 million ha and 500 million ha, respectively, providing a biomass potential of more than 5% (Field et al., 2008) of the global energy consumption in 2005.

Up to now, semi-natural grassland material has not been used for bio-energy generation to a large extent due to technical difficulties and economical restrictions of its use in conventional bio-energy conversion systems. The late cut fibre-rich material is detrimental for an efficient anaerobic digestion, and high concentrations of elements causing corrosion or hazardous emissions restrain combustion performances (Richter et al., 2009).

The study at hand intended to economically assess a newly developed technological procedure that provides energy from semi-natural grasslands according to the integrated generation of solid fuel and biogas from biomass (IFBB) (Wachendorf et al., 2009). Unlike conventional biogas systems that cannot cope very well with biomasses low in digestibility the IFBB procedure is especially suitable for the application of extensive grassland material. The biomass is mechanically dehydrated after a hydrothermal conditioning process to elutriate mineral components unfavourable for combustion purposes. The attained press fluid, which exhibits higher digestibility and increased methane yields compared to whole crop digestion (Richter et al., 2009), is used for biogas production. The press cake is turned into a solid fuel with improved combustion characteristics, which are displayed by considerable reductions of mineral compounds such as potassium (80%), magnesium (61%) and chloride (81%) and reductions in emission-relevant constituents such as nitrogen (19%) and sulphur (39%), as well as significantly increased ash softening temperatures up to 1250 °C compared to the untreated material (Richter et al., 2010, 2011a). Both semi-natural grassland and green cut material proved to attain higher net energy yields and conversion efficiencies through hydrothermal conditioning and mechanical dehydration within the IFBB system than in whole crop digestion systems (Bühle et al., 2011; Hensgen et al., 2011; Richter et al., 2011b). Economic assessments of various forms of high nature value grassland utilisation have so far concentrated on management options of animal husbandry systems including forage use by mowing and grazing (Hodgson et al., 2005; Rühs et al., 2005; Caballero, 2008), co-substrate application along with liquid manure or maize in conventional biogas production systems (Blokhina et al., 2009) or hay combustion (Prochnow et al., 2009b), as well as other landscape preservation management options, such as rototilling or combinations of rototilling and mowing regimes (Schröder et al., 2008). In this study economic assessments for the IFBB system in comparison to other bio-energy systems (dry fermentation, hay combustion), an animal husbandry system (beef cattle) and two non-refining management systems (mulching, composting) were conducted. The study focused on German framework conditions concerning a variety of economic input parameters. Profitability calculations, comparing economic key figures and interactions of changing framework conditions on economics by sensitivity analysis were covered by this study.

2. Methods

The study was based on dynamic investment calculations (VDI, 2002) and assumptions generated through expert interviews, providing a comparative setting and display of performances of seven examined grassland production or maintenance systems: (1) energy recovery by the IFBB technology as a stand-alone system (IFBB-SA), (2) energy recovery by the IFBB technology as an add-on system to an agricultural biogas plant (IFBB-AO), (3) energy recovery by dry fermentation (DF), (4) energy recovery by hay pellets production and combustion (HC), (5) animal-based utilisation by beef cattle (BC), (6) mulching of the grassland (MU) and (7) composting and fertiliser production (CO) (Fig. 1). Below, the framework assumptions, the economic simulation model as well as sensitivity parameters are defined and the system descriptions are carried out.

2.1. Biomass feedstock

Semi-natural grasslands as biomass feedstock referred to in this study were established and managed for decades by cutting and removing the biomass for feeding purposes. Data used within the economic simulation model were generated within the European project PROGRASS (Bühle et al., 2012), describing the average of a broad assessment of European grasslands by 18 sites in Germany, Wales and Estonia over three years. These grassland sites were mainly situated in the European NATURA 2000 sanctuary system. Grassland was cut once a year in July with a gross biomass yield of 3.8 t DM ha^{-1} yr^{-1}. Current grassland subsidies, comprising of 85 € ha^{-1} yr^{-1} from the European direct payment scheme (EC, 2009) as well as an average of 250 € ha^{-1} yr^{-1} from agri-environmental schemes (HMUELV, 2009), were considered in the grassland production calculations. Harvest or management mechanisation for each system was calculated according to standard agricultural field operation data (Table 1). The average field-farm distance was set at 5 km. Land area requirements were calculated according to the methane (CH_4) yields converted by a 50 kW_{el} Combined Heat and Power plant (CHP) and then transferred to all other analysed land use systems.

2.2. Economic simulation model

In order to compare the land use systems, an economic simulation model was developed based on the annuity method according to the guidelines for *economy calculation systems for capital goods and plants* (VDI, 2002). Applying this method, the results will be comparable to other standardised calculations. The annuity method considers discounting as well as changes in interest and price rates of all non-recurring and regular payments during the complete observation period of an investment by transforming all future information into a periodically constant business ratio, allowing for the rating of the attractiveness of an investment. If the total annuity is >0 the investment is profitable, at a total annuity of 0 an investor would be indifferent about an investment decision. Displaying the profitability key figures of the Return On Investment (ROI) and Return On Equity (ROE), the Internal Rate of Return (IRR) as well as the Internal Rate of Return to equity, respectively, were calculated according to Wöhe (2005) and Mußhoff and Hirschauer (2010). Calculations of the IRR were based on the gross Free Cash Flow (FCF), and of the IRR to equity on the investor's dividend payouts