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Commercial viability of paludiculture: A comparison of harvesting reeds for biogas production, direct combustion, and thatching

Sabine Wichmann[a,b,*]

[a] DUENE e.V. and Institute of Botany and Landscape Ecology, Ernst Moritz Arndt University, Partner in the Greifswald Mire Centre, Soldmannstraße 15, D-17487 Greifswald, Germany
[b] Institute of Sustainable Development of Landscapes of the Earth (DUENE e.V.), Soldmannstraße 15, 17489 Greifswald, Germany

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ABSTRACT

Since disservices and the finite nature of agriculture on drained peatlands are increasingly recognised, land use options for wet or rewetted peatlands (paludiculture) are recommended as sustainable alternatives. Their economic viability at the farm level, however, is largely unknown. This paper addresses managing reed-dominated (*Phragmites australis*) vegetation stands with special-purpose tracked machinery in central Europe. Three options of biomass harvest for energetic and material use were investigated. Contribution margin accounting estimated the income left after subtracting variable costs and fixed machinery costs. Stochastic scenario analysis (Monte Carlo method) revealed a wide range of possible outcomes from ca. € −1000 to € 1500 ha^{-1} yr^{-1}. Harvesting summer reed for biogas production is the least profitable option, winter mowing for direct combustion can be cost-efficient, and reed for thatching is clearly the most profitable. Cumulative probability distributions identified risks of 98%, 18%, and <1% respectively, that revenues for biomass cannot cover harvesting costs. The feasibility and competitiveness of the three harvesting regimes are principally influenced by the availability of mature technology, legal restrictions, the entitlement to agricultural subsidies, a remuneration of external benefits, and the opportunity costs of present farming activities. Therefore, laws and policies determine whether a balanced provision of ecosystem services is hindered or promoted in peatlands used for agriculture.

1. Introduction

Draining peatlands for agriculture has caused the successive degradation of ecosystem functions. The resulting loss of biodiversity, nutrient discharge, greenhouse gas emissions, soil degradation, and subsidence have led to increasing recognition of and value placed on ecosystem services provided by wet peatlands (Maltby, 1986; Joosten and Clarke, 2002; Groot et al., 2006; Turner et al., 2008). Paludiculture, i.e. agriculture on wet or rewetted peatlands (Wichtmann and Joosten, 2007), has the potential to balance provisioning, regulating, and cultural services (Luthardt and Wichmann, 2016); keep organic soils in long-term use (Joosten et al., 2012); and sustainably produce biomass for renewable energy or as a raw material (Wichtmann and Wichmann, 2011). For decades, scientists have suggested to cultivate wetland-adapted crops and refine traditional uses (Morton and Snyder, 1976; Kresovich et al., 1981; Porter et al., 1992; Verhoeven and Setter, 2009; Knox et al., 2015). In recent years, however, major international bodies have recommended paludiculture as a viable option (EU, 2013; FAO: Biancalani and Avagyan, 2014; IPCC, 2014; IUCN: Cris et al., 2014).

Since land users adopt sustainable practices on peatlands only "if they are practical and financially viable" (Rawlins and Morris, 2010), the issue is the extent to which paludiculture – besides providing external benefits – is profitable at the farm level. The database of potential paludicultural plants (Abel et al., 2013) contains 800 species that thrive under wet conditions and indicates appropriate options for using their biomass. In particular, cultivating emergent wetland plants as a bioenergy source and building or insulation material is both feasible and practical (Wichtmann and Schäfer, 2007; Wichtmann and Tanneberger, 2011). An economic harvest of taxa such as reed (*Phragmites australis*), cattail (*Typha* spp.), and sedges (*Carex* spp.) requires efficient machines that are adapted to saturated organic soils by having a low ground pressure. 'Seiga' machines, equipped with balloon tyres, have been used to harvest thatching reed since the 1950s (Björk and Granéli, 1978). Modified snow groomers and newly developed special-purpose tracked machinery are increasingly used for biomass harvest (Wichmann et al., 2016), including the large-scale conservation management of fens (Kotowski et al., 2013).

* Tel.: +49 3834 86 4143; fax: +49 3834 86 4107.
E-mail address: wichmann@uni-greifswald.de

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Research has focused on the influence of biomass harvest on productivity and stand structure (Engloner, 2009), botanical diversity (Kotowski et al., 2013), wildlife (Valkama et al., 2008), nutrients (Vymazal, 2005), and greenhouse gas emissions (Günther et al., 2014), but the economics of wetland management has been largely neglected. To date, no study exists with reliable data on the costs of biomass removal based on large-scale and long-term experience with special-purpose machinery. This article explores the cost-effectiveness of harvesting reeds in central Europe, identifies the variables with the greatest influence on profitability, compares advantages and disadvantages of three harvesting regimes, and discusses aspects that influence their feasibility and competiveness.

2. Materials and methods

2.1. Harvesting regimes

Economic costs and benefits were estimated for the harvest of reed-dominated vegetation stands with tracked vehicles. These machines are suitable for an efficient, large-scale harvest and are equipped with specific devices adapted for the intended use of biomass (Fig. 1). The three options of biomass utilisation considered are applied by pioneering commercial plants (biogas production, combustion) or widely established with an international market (thatching):

(a) Chopped biomass for biogas production ['chaff']

Green biomass is cut in summer with a rotary mower or cutter bar and is then windrowed in one pass. In a second pass, the swath is picked up by a forage wagon or gathered by a chopper and placed into a trailer (Fig. 1a and b). The finely chopped biomass is processed in biogas plants adapted to green grass-like material to generate electricity and heat.

(b) Round bales for direct combustion ['bales']

Biomass is harvested on dry winter days, when its moisture content is sufficiently low to prevent excessive heating and moulding during storage, and to cut and press it into round bales in a single pass (Fig. 1c and d). A separate vehicle equipped with a crane picks up the bales and transports them to the edge of the field. The bales are burnt in combustion plants designed to generate heat (and in the high power range also electricity) from materials such as straw or *Miscanthus*.

(c) Bundles for thatching ['bundles']

Thatching reed is harvested in winter when the leaves have fallen and the moisture content is low. In one pass, the long, straight culms are mown with a cutter bar, brushed for an initial cleaning and bound into bundles with a circumference of approximately 65–70 cm (Fig. 1e and f). Several hundred bundles are bound into one large bale and transported to the edge of the field with a separate vehicle. After the harvest and further drying, bundles are opened, cleaned and bound into tight bundles (55–60 cm circumference) ready for sale and thatching.

2.2. Data collection

In-depth, semi-structured interviews were conducted with reed cutters and landscape managers with extensive (20–30 years) experience in wetland-adapted machinery, site productivity and revenues (Germany: n = 6, Netherlands: n = 2, Poland: n = 1, Austria: n = 1). A standardised questionnaire was sent to all biogas plants in the German federal state of Mecklenburg-Western Pomerania (n = 237, 19% response rate) to investigate the current use of grass-like biomass in NE Germany and the willingness to accept biomass from paludiculture. Labour time and acreage performance (e.g. the time required for mowing, chopping and transporting biomass) were measured during field tests for the 'chaff' and 'bundles' harvesting regimes using GPS tracking (logger Wintec WBT-202) and a stopwatch. Literature was used to verify estimates of biomass productivity, revenues, and harvesting performance.

Table 1
Extended contribution margin (CM) accounting to estimate profitability: revenues have to cover not only variable costs (CM I) but also fixed costs of specialised, single-purpose machinery (CM II).

Revenues from the sale of biomass:
Biomass yield × price
Minus variable costs:
− direct costs (seedlings, fertiliser, pesticides)[a]
− variable machinery costs
− labour costs
= Contribution margin I
Minus attributable fixed costs:
− fixed machinery costs
= Contribution margin II

[a] Not applicable, since harvest of existing vegetation stands is assumed.

2.3. System boundaries

Cost accounting was performed to calculate harvesting costs and to compare the expenses and revenues of each regime. Operating costs included all costs of harvesting, transporting (to the field edge) and processing needed to sell the biomass for energy or material use. Costs of further transport and storage vary widely; in specific cases they can be calculated using data for handling silage, straw, or hay in conventional agriculture.

The calculations included variable machinery costs (e.g. fuel, machine care) and labour costs, which changed with the production volume, and fixed machinery costs (e.g. depreciation, insurance), since they could be assigned directly to the harvesting regimes (Table 1). General and administrative costs, which vary considerably among companies, and site-specific costs or revenues (e.g. land lease, direct payments) were excluded.

2.4. Stochastic simulation

Stochastic scenario analysis was performed using Monte Carlo simulations (Hardaker et al., 2004) to account for uncertainty in and ranges of data. Each input variable of the CM II calculation model was given a range of values and a probability distribution (Tables 3 and 4). Depending on the variable and data quality, the probability distribution was defined as uniform (e.g. purchase costs of machinery) or triangular (e.g. yield) by setting maximum and minimum values (and the mode, for the latter). Simple positive or negative correlation factors were assumed to express interdependence between single variables (Table 2), e.g. higher biomass yield requiring more time to harvest and consequently inducing higher harvesting costs per hectare. In calculating the fixed machinery costs, expensive machinery was assumed to have more operating hours per year and a higher residual value.

Computer-based Monte-Carlo simulations were performed with @RISK 6 software (Palisade Corporation, Ithaca, New York, USA) used as an add-in for spreadsheet software (Microsoft® Office Excel 2013). A large number of iterations (10,000) were generated for each harvesting regime. Input values were randomly selected according to the conditions defined for each parameter. Use of the Latin hypercube method ensured stratified random sampling