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The energy balance of utilising meadow grass in Danish biogas production

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ABSTRACT

This paper presents a study of the energy balance of utilising nature conservation biomass from meadow habitats in Danish biogas production. Utilisation of nature conservation grass in biogas production in Denmark represents an interesting perspective for enhancing nature conservation of the open grassland habitats, while introducing an alternative to the use of intensively cultivated energy crops as co-substrates in manure based biogas plants. The energy balance of utilising nature conservation grass was investigated by using: data collected from previous investigations on the productivity of meadow areas, different relevant geo-datasets, spatial analyses, and various statistical analyses. The results show that values for the energy return on energy invested (EROEI) ranging from 1.7 to 3.3 can be obtained when utilising meadow grasses in local biogas production. The total national net energy gain (NEG) was estimated to more than 600,000 GJ corresponding to ≈15% of the total Danish biogas production in 2012.

1. Introduction

The lack of nature conservation in the form of grazing or hay harvest is considered to be one of the biggest threats towards the biodiversity of the open natural and semi-natural grassland habitats in Denmark (Ejrnæs et al., 2011). Despite the habitats being protected by the Nature Conservation Act, there are no rules for continued grazing or mowing after agricultural use has ceased (The Danish Ministry of the Environment, 2013). Due to natural succession and eutrophication, habitats which are no longer mowed or grazed are at a risk of changing character from having a high biodiversity with low vegetation into being overgrown by dominating tall and fast growing plant species (Ellemann et al., 2001).

The presence of grazing animals has had a strong impact on the Danish landscape and the existence of the grasslands. Before the implementation of agriculture, open grassland habitats emerged from wild ruminants grazing on the clearings in the woodlands. The population of beavers also had an impact on these habitats. The beavers cut down smaller trees and bushes and built dams which caused the lowland habitats to be flooded. These circumstances helped creating and maintaining open grassland habitats. During the Iron Age (≈500 BC–800 AD) Denmark changed character into being a more highly populated peasant society and land use increased. Agricultural practices were implemented and the natural and semi-natural grasslands played an important role in the agricultural production. The grasslands were grazed by the livestock population or mowed for hay production that was fed to the livestock over the winter season. The animal manure was collected in the stables and applied as fertiliser on the arable land where food crops were cultivated. The grassland habitats were thus functioning as a provider of both ruminant fodder and fertiliser for the arable land. In the late 1800s the agricultural sector started industrialising and the habitats lost their importance for livestock production as more efficient feedstock could be cultivated on the arable land. Over time the majority of the natural and semi-natural grasslands were either taken out of production or drained and cultivated intensively (Buttenschøn, 2007; Nygaard et al., 2011). Non-grazing on open grasslands (by either wild ruminants or livestock) have resulted in a decline of their biodiversity. In 2010, Ejrnæs et al. (2011) assessed the status of the biodiversity on open natural and semi-natural habitats (grassland, heather, bog and meadow). They found that the biodiversity was declining by 61–70% in terms of the assessed elements due to overgrowth, drainage or eutrophication of the areas. The open natural and semi-natural habitats are however essential for the existence of the natural flora and fauna in Denmark, as the landscape is strongly dominated by intensive agricultural utilisation. Thus conservation of these habitats is of urgent importance.

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Grass from nature conservation and landscape management has been shown to be a suitable feedstock for anaerobic digestion (Møller and Nielsen, 2008; Jørgensen et al., 2008). Large variations in the obtainable methane yields have however been reported to be dependent on the maturity of the vegetation: 60–309 L/kg VS (Herrmann et al., 2014), 155–293 L/kg VS (Prochnow et al., 2005). The concept of utilising nature conservation grass in biogas production in Denmark nevertheless represents an interesting perspective for enhancing the nature conservation of the open grassland habitats, while introducing an alternative to the use of intensively cultivated energy crops as a co-substrate in manure based biogas plants. It furthermore allows for a redistribution of nutrients from the soil of the habitats to the cultivated land as digested fertilizer. The possibility of utilising nature conservation grass for biogas production fits well into the current energy policy for the biogas sector in Denmark. As the Danish Government is aiming at increasing the share of available animal manure used for anaerobic digestion to 50% by 2020 (The Danish Ministry of Climate Energy and Buildings, 2012; Jacobsen et al., 2013) co-substrates with high concentrations of organic volatile solids (e.g. grasses or maize) for boosting the methane production are needed. However, only 12% of the total input in the biogas plants may consist of energy crops (The Danish Energy Agency, 2012). Industrial organic waste streams have typically been used as co-substrates in the Danish biogas production; therefore the quantities of unutilised industrial organic waste are limited. Due to this fact, alternative co-substrates must be found if the biogas sector is to expand according to the Danish energy policy. Using nature conservation grasses as co-substrates could be part of the solution to this issue, while providing other positive externalities (reducing loss of biodiversity, nutrient recycling) and without competing with the current land use. The concept of utilising grasses from nature habitats could thus function as a provider of renewable energy, a method for increasing the biodiversity of the nature habitats, and as a method for redistributing nutrients from sensitive natural and aquatic environments to the agricultural land.

Several challenges can however be related to the prospects of utilising nature habitats for biomass production. The geographical distribution of the habitats, transport distances, access to a road network, navigability and habitat size are factors that could complicate the actual acquisition of the nature conservation biomass (Meyer and Holm-Nielsen, 2013), as it could be very energy consuming to acquire the biomass. Furthermore it can be difficult to assess the actual biomass yields that can be obtained from natural habitats.

The aim of this paper is to evaluate the energy balance of utilising nature conservation grasses from meadow habitats in Denmark (coastal meadows and fresh water meadows) for anaerobic digestion in the existing Danish biogas plants. This is done by investigating the following issues of concern for the concept:

- The area and distribution of meadow habitats in Denmark.
- The obtainable grass yields from meadow habitats.
- Factors influencing the obtainable yields of meadow grass.
- The energy requirements related to the acquisition and utilisation of nature conservation biomass.
- The energy yields from anaerobic digestion of nature conservation grasses?

2. Data and methods

The methods applied in this study consist of spatial and statistical analyses. The spatial analysis was conducted in order to identify the location of the grassland habitats, their size, distance to both a biogas plant, and the road network (described in Section 2.1). Various statistical methods (described in Section 2.2) were applied for assessing the potentially obtainable biomass yields as well as for identifying the factors that influence the achievable biomass yields from meadow habitats. The spatial and statistical analyses and the corresponding results were applied to assess the yields of biomass that can be obtained (Section 2.3) and to estimate the energy balances of utilising nature conservation biomass from meadow habitats in biogas production (Section 2.4).

2.1. Spatial analyses of grassland habitats in Denmark

Spatial analyses was conducted by using *ESRI ArcMap 10.2.1® software*. All geo-datasets were projected to the coordinate system ETRS89 UTM zone 32N. The analyses were performed in order to assess the size of the coastal and fresh water meadows, the proximity to both the nearest biogas plant, and to the road network. The purpose of the analyses and the methods applied are presented in the following subsections.

2.1.1. Identification of meadow habitats in Denmark

The geo-dataset *Basemap* (Levin et al., 2012) was applied to identify the habitats defined as fresh water or coastal meadow in Denmark. The geo-dataset shows the land cover and land use of Denmark, and was created by the Department of Environmental Science at Aarhus University and the Department of Geography and Geology at the University of Copenhagen. The fresh water and coastal meadows were selected in the *Basemap* dataset and exported into a new basemap dataset. The size of the meadow habitats was found by calculating the geometry of the identified habitats.

2.1.2. The need for nature conservation

A complete assessment of the need for nature conservation on meadow habitats has not yet been conducted in Denmark. However, based on inspections of the nature quality in subsets of the meadow habitats in Denmark conducted by the Danish state and municipalities, Nygaard et al. (2011) evaluated the need of nature conservation (in terms of grazing and harvest) on Danish meadows by scaling up the results of the local nature quality inspections to national level.

This evaluation cannot be used to identify the particular conservation method that should be applied on a specific meadow habitat. As long as no comprehensive assessment of the nature quality on all meadow habitats is available, the evaluation by Nygaard et al. (2011) is at best an indicator of the nature conservation needs. The preconditions for evaluating the appropriate type of conservation method are based on the quality of the habitats. For habitats with a good or high nature quality, grazing is considered to be the best management practice. Such areas can be sensitive to harvest machinery, and thus harvest is not the preferred conservation method. For areas with moderate or low nature quality, harvest or harvest combined with grazing is considered to be the suitable management practice in order to ensure removal of soil nutrients causing eutrophication.

The evaluated allocation of nature conservation methods for the total area of fresh water and coastal meadows in Denmark expressed in percentages is presented in Table 1.

The need for nature conservation is relevant in this study, as it indicates the habitats from which biomass can be obtained via harvest. This evaluation was therefore applied for estimating the size of the habitats from which biomass can be obtained through harvesting practices. The percentage of the total meadow area evaluated to benefit from combined grazing and harvest, or only harvest, was assumed to be the area from which biomass can be obtained via harvest. Although this method will not represent how the actual conservation needs are distributed, it is considered to be the most