INFLUENCE OF DIFFERENT BIOMASS TREATMENT TECHNOLOGIES ON EFFICIENCY OF BIOGAS PRODUCTION

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Abstract. The results of the influence of fresh grass, hay and silage of reed canary grass (*Phalaris arundinacea* L.) on the efficiency of anaerobic digestion are presented in the paper. The environmental assessment of biogas production technology has been analysed in terms of life cycle assessment methodology as well. Energetic evaluation has been performed including direct and indirect energy inputs of all technological operations from soil preparation to anaerobic digestion. The schemes of anaerobic digestion for three types of grass treatment technologies have been designed. It is determined that emissions of direct energy input during the digestion grass silos and fresh grass – 0.049 and 0.041 kgCO_2 per kg of biomass were the highest. The highest gas leakage was found to be in the dried grass digestion case – 0.0241 kgCO_2 per kg of biomass. The ratio of reduction of greenhouse gas emissions was the highest for the dried grass digestion to biogas – 4.55 kgCO_2 per kg of biomass. The results of the analysis of the total energy input for plant biomass anaerobic digestion and energy potential of biomass shows that the energy conversion efficiency of biogas production is the highest at the dried grass (6.8) technology, and the lowest at fresh grass – 5.5. These results suggest that anaerobic digestion to biogas is an energy efficient and environment friendly way of biomass utilization and renewable energy creation.

Keywords: biomass, biogas, efficiency, treatment technologies.

Introduction

Plant biomass is widely used in the renewable energy production sector and recently dominates in many countries energy balance [1]. The countries of the European Union (EU 27) have agreed on increasing the contribution of renewable sources from final energy consumption by 20 % by 2010 where biomass will be one of the major contributors [2]. Biomass use in the EU 27 accounts approximately for 95.7 Mtoe recently [3]. Direct combustion of biomass releases the same amount of CO_2 into the atmosphere that earlier has been taken up by the plants. The entire life cycle of biogas production from plant biomass taking into account crop cultivation and through conversion into energy, the substantial amounts of non-renewable energy resources are used. Such resources cause greenhouse gas (GHG) emissions [4]. Thus, biofuels are not CO_2 neutral from a life-cycle point of view.

Increasing biomass usage leads to reduction of greenhouse gases emissions compared to the use of fossil fuels. Environmental and energetic evaluation of biogas production technology can be analysed in terms of life cycle assessment (LCA) [5]. There are studies made on environmental impact assessment of biogas production technologies from maize [6] and biogas injection to the grid compared to natural gas [7] or as transport fuel [8; 9] alone or comparing with fossil fuels [10, 11]. Energetic evaluation of biogas production from plant biomass has to take in the total energy input related to full cycle – from soil cultivation up to conversion to biogas. The direct and indirect energy inputs of all technological operations and equipment have to be included in the analysis [12 – 15]. Dubrovskis et al. [16] analysed GHG saving according to natural gas GHG emissions, where they found that GHG emission savings for biogas from corn, wastewater waste, manure or municipal solid waste were 71.2 %, 84.4 %, 86.2 or 73.3 % compared to natural gas usage respectively.

The aim of the paper is to perform and present the methodology of environmental and energetic evaluation of biogas production from plant biomass.

Methods

Environmental and energetic evaluation of biogas production technology from three biomass treatment technologies is performed according to the reduction of greenhouse gasses. The technological scheme of plant biomass anaerobic digestion to biogas is designed depending on the features and the place of biomass production. Therefore, the environmental and energetic efficiency of biomass digestion depends on the treatment technology. At different technologies variation of the equipment and machinery used occurs, thus the energy input differs as well. During the summer season grass can be cut few times. Fresh grass after cut is transported directly to the biomass mixing-dosing device at the biogas plant and inserted to the digester. According to ensiling practice, grass is wilting then collecting to trailers and transporting for ensiling. Silage from the tranche by tractor is loaded to the stationary biomass mixing-dosing device and later transferred to anaerobic digesters. Dried biomass (hey) has to be prepared on the fields as it needs few days to dry naturally. Later hey is transported to the storage place for further storage. The anaerobic digestion process for all three types of biomass is the same. After anaerobic digestion the digested substrate is pumped to the digestate storage tank. From the storage tank the digestate by slurry tankers is transported to the fields where crops are fertilized. The produced biogas is used for electricity and heat production in cogenerators. Electricity and heat are consumed by some technological equipment in the biogas plant and surplus can be sold to the public electricity grid.

Schematically the plant biomass treatment cycle can be divided into four stages: plant cultivation, harvesting and treatment, storage and finally digestion to biogas (Fig. 1). Energy input (*E*) and greenhouse gas (GHG) emissions (*e*) occur at all stages and processes.

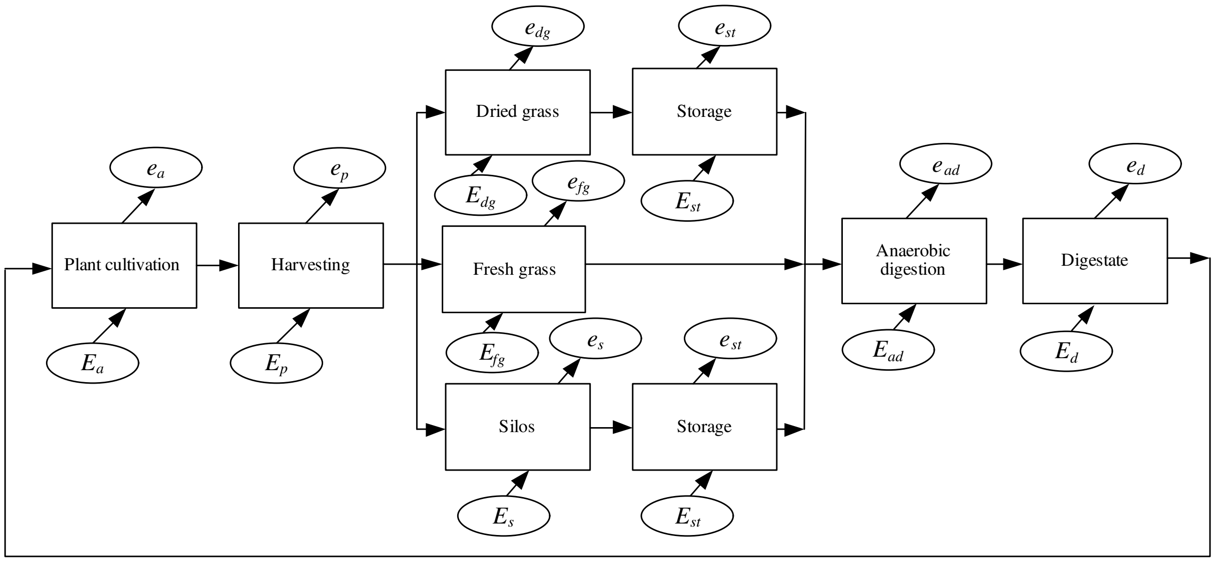

Fig. 1. **Scheme of energy inputs and greenhouse gas emissions for three types of biomass treatment technologies**

Energetic evaluation of biogas production from plant biomass is done after determination of the total energy input for plant cultivation and conversion to biogas. Energy consumption includes direct and indirect energy inputs for all processes. The gaseous emissions of global warming gases of direct and indirect energy consumption have been analysed as well. Emissions of gases are expressed as equivalent mass of CO_2. During the anaerobic digestion of plant biomass the emissions of GHG can be determined by the evaluation of CH_4 and CO_2 gas yields, gas leakages and emissions of energy input. The reduction of GHG emissions at anaerobic digestion of biomass can be expressed as:

$$\Delta e = e_{CH_4} - e_{leak} - e_{CO_2}^{d} - e_{CO_2}^{in} , \tag{1}$$

where e_{CH_4} – equivalent methane (CH_4) yield from biomass, expressed in CO_2, kgCO_2 per kg of biomass;

e_{leak} – gas leakage during the anaerobic digestion process, kgCO_2 per kg of biomass;

$e_{CO_2}^{d}$ – gas emissions of direct energy input of the anaerobic digestion process, kgCO_2 per kg of biomass;

$e_{CO_2}^{in}$ – gas emissions of indirect energy input of the anaerobic digestion process, kgCO_2 per kg of biomass.

Emissions of carbon dioxide from biomass are considered as neutral. Independently of organic material degradation time-span, the overall CO_2 quantity remains unchanged, i.e., does not depend on the type and speed of degradation – by burning or natural degradation in few decades. However, other CO_2 emissions that do not originate from biomass degradation have to be evaluated such as construction of techniques, production of fertiliser and chemicals and usage of electricity and liquid fuels.

Energy production from biogas leads to reduction of the consumption of mineral fuel. The methodology of emission of avoided mineral fuel by replacing the same amount of energy to biogas has been presented by [17]. Production and usage of biogas for energy production can replace a certain amount of energy from mineral fuel. The reduction of emissions after replacement of mineral fuel by biogas is calculated according the methodology of Navickas et al. [17].

Direct and indirect energy inputs at all stages (according to Fig. 1) have been analysed according to the methodology presented earlier by Navickas et al. [18].

Calculations were performed assuming that Reed canary grasses have been cut twice per season and the obtainable total biomass yield of total solids – 8 $tTS \cdot ha^{-1}$.

Results and discussions

Analyzing plant biomass digestion to biogas the total energy input at establishment of plants, yield harvesting, drying, ensiling of biomass and anaerobic digestion at biogas plant have been taken into account.

The reduction rates of environmental pollution have been determined. The main and the highest part of gaseous emissions are gas leakages and emissions of direct energy input (Fig. 2).

The highest leakage gas emissions were found to be in the dried grass digestion case – 0.241 $kgCO_2$ per kg of biomass. This causes the relatively higher concentration of TS (96.2 % TS) and energetic value of biomass (10.28 $MJ \cdot kg^{-1}$) compared to other grass treatment types. Fresh grass and silos had noticeably lower TS concentration – 39.2 % and 27.2 % respectively. The energetic value of fresh grass was 4.23 $MJ \cdot kg^{-1}$ and of silos – 4.25 $MJ \cdot kg^{-1}$ what has direct influence on gas leakage emissions – 0.10 and 0.09 $kgCO_2$ per kg of biomass respectively. GHG emissions of gas leakage according to [19] methane leakage can reach up to 5 % from the produced methane in the biogas plant.

The highest emissions of direct energy input are from silage anaerobic digestion (0.049 $kgCO_2$ per kg of biomass) as the technology is the most energy consuming among other technologies. Emissions of direct energy consumption of fresh grass biomass digestion are 0.041 $kgCO_2$ per kg of biomass and dried biomass – 0.027 $kgCO_2$ per kg of biomass. Dried grass has the lowest energy input for transportation as the mass is reduced at drying in the field.

The emissions of indirect energy input are relatively low ($7.8 \cdot 10^{-4}$ $kgCO_2$ per kg of biomass) and little dependent on the anaerobic digestion technology of grass.

The reduction of greenhouse gas emissions Δe is the highest for the dried grass digestion – 4.55 $kgCO_2$ per kg of biomass (Fig. 3). Reduction of greenhouse gas emissions of fresh grass treatment is 1.88 $kgCO_2$ per kg of biomass and the lowest of silage – 1.84 $kgCO_2$ per kg of biomass.

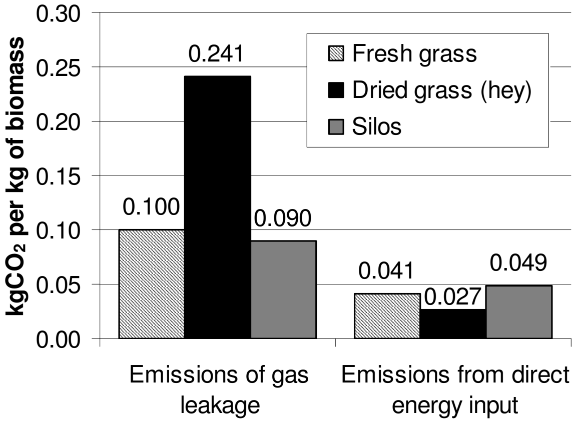

Fig. 2. **Greenhouse gas emissions of anaerobic digestion of biomass**

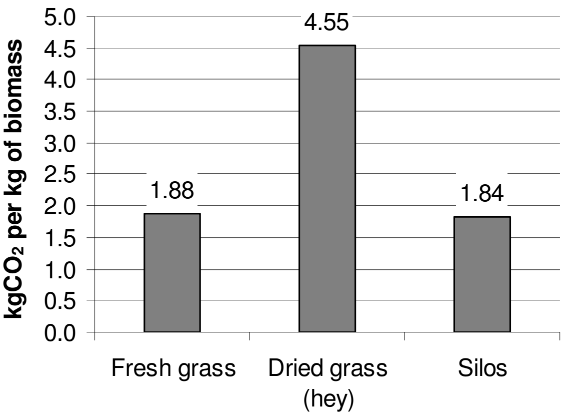

Fig. 3. **Reduction of greenhouse gas emissions Δ*e***

Energy balance has been expressed as difference between the total energy input and energy potential from biomass (Fig. 5).

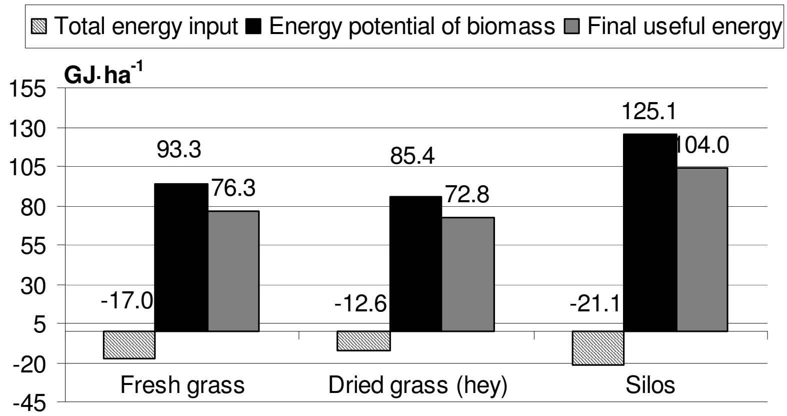

Fig. 5. **Energy balance of three treatment technologies of grasses**

A high amount of mineral fuel can be replaced by using the produced biogas for energy production. It is identified that by the exploitation of the energetic potential of plant biomass it is possible to reduce CO_2 emissions. The reduction for all three types of treatment technologies is relatively the same and varies in the range from 27.2 to 27.8 times compared to gaseous emissions of mineral fuel.

The energy potential of fresh grass, dried grass and silos is 93.3, 85.4 and 125.1 $GJ \cdot ha^{-1}$ and total energy input 17.0, 12.6 and 21.1 $GJ \cdot ha^{-1}$ respectively. Therefore, the calculated ratio of energy conversion efficiency of biogas production is the highest at dried grass (6.8) technology, and the lowest at fresh grass – 5.5. Silos has the highest energy potential (125.1 $GJ \cdot ha^{-1}$), but at the same time it uses the most of energy (21.1 $GJ \cdot ha^{-1}$), therefore the energy conversion ratio (5.9) is not the best among the analysed systems.

Conclusions

1. It is determined that anaerobic digestion of plant biomass to biogas reduces greenhouse gas emissions. The highest reduction effect has been found at digestion of dried grass – 4.55 $kgCO_2$ per kg of biomass. For the other grass treatment technologies the ratio has been lower – 1.84 – 1.88 $kgCO_2$ per kg of biomass.
2. The highest gas leakage emissions have been found to be from those treatment technologies which have higher concentration of total solids thus higher biogas yield is obtainable from biomass. The highest leakage was found to be in the dried biomass digestion case – 0.241 $kgCO_2$ per kg of biomass.
3. It is identified that by exploitation of the energetic potential of plant biomass it is possible to reduce CO_2 emissions approximately 27 times compared to gaseous emissions of burning mineral fuel.
4. The results show that the ratio of energy conversion expressed as difference between the total energy input and energy potential from biomass is the highest for the dried grass digestion technology and reaches 6.8.

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