GHG EMISSIONS FROM THE USAGE OF ENERGY CROPS FOR BIOGAS PRODUCTION

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Abstract
Greenhouse gas (GHG) emissions have been evaluated for usage of maize, natural grasses, perennial legumes lupine and galega for biogas production in cogeneration a unit with electric power of 500 kW in a 20 years period. The area for biomass supply to the cogeneration plant varied from 314 ha for maize to 2 219 ha for natural grasses growing without fertilization. The type of biomass strongly influences GHG emissions because of the different number of treatments needed for energy crop growing, transportation distances, fertilization needs and various levels of carbon capture into the soil. It was found that maize biomass usage for energy production caused the highest GHG emissions 24 gCO_{2eq} MJ^{-1} which can be explained by high number of treatments and increased mineral fertilizer doses needed for intensive growing of biomass. The usage of perennial galega and lupine resulted in negative emissions because of the ability of legumes to provide self-supply with nitrogen and to capture carbon into the soil. GHG emissions per unit of area in a year are varying from -0.92 tCO_{2eq} ha^{-1} for galega usage to 1.55 tCO_{2eq} ha^{-1} for maize usage for biogas production.
Key words: GHG emissions, energy crops, biogas.

Introduction

For biogas production from biomass applies sustainability criteria that from 1 January 2017, the greenhouse gas emission saving from the use of biofuels shall be at least 50 %, and from 1 January 2018 saving shall be at least 60% for biofuels produced in installations in which production started on or after 1 January 2017 (Cabinet Regulations, 2011). The following principle was elaborated for biomass usage for energy production: “Natural resources, such as soil, water and land, shall be used efficiently and biomass production or extraction shall not endanger soil or cause further deterioration to water quality and quantity” (Rosenberg, 2009). Around 174 000 ha of unused agricultural land areas were available for growing of different energy crops without affecting the food or fodder production in Latvia in 2010. Energy crops shall be tolerant to weeds, pests, diseases, drought and frost, have good winter hardiness and be able to grow with low nutrient input. Maize is recognized as viable energy crop for biogas production in middle part of Latvia in region Zemgale. However, more severe climatic conditions, uneven land surface, low soil fertility and acidified soils impose the constraints for cultivation of the maize in regions Vidzeme and Latgale at east part of Latvia. Different energy plants, e.g. perennial grasses and legumes can be raised instead of the maize to provide feedstock for biogas plants in those regions. All perennial plants have positive effect on soil humus content, and legumes further are able to enrich the soil with nitrogen. Perennial lupine sustains in acidified soils with low organic matter content, and perennial legume galega can to provide high biomass yields during 20 - 25 years period without the need for soil ploughing (Adamovics, 2008). Perennial grasses biomass can be obtained from natural meadows or semi-natural grasslands, including areas with high biodiversity. There is potential possibility to obtain biomass also from grasslands with the high biodiversity. Removing of biomass from perennial semi-natural grasslands, instead of the cut biomass spreading, provides the better biodiversity and can be regarded as the most suitable management method (Rūsiņa, 2008). Implementation of biomass to biogas technologies are supported by EU and Latvian financial aids since year 2009. The size of biogas plant with electric power of 500 kW is considered as the most viable, due to acceptable transportation distances for biomass feedstock and digestate in rural areas in Latvia. Choice of the suitable energy crop is of high importance for planning of cogeneration plant capacity and evaluation of minimal area needed to provide round-year running of cogeneration plant at minimal greenhouse gases emission level. GHG emissions sources from biomass growing, harvesting and pretreatment for utilization in biogas cogeneration plants. However, intensive and continuous arable production may lead to a decline of soil organic matter. In 2009, European cropland emitted an average of 0.45 tons of CO2 per hectare and much of which resulted from land conversion. Such the significant losses of soil organic matter in soils may impair achievement of the EU’s Kyoto Protocol targets (COM 46, 2012). Soil has low average soil organic content in Latvia, therefore different energy crops usage for bioenergy production should be evaluated. Soil organic matter changes should be included in GHG emissions calculations also to identify the following sustainability indicator accepted by Global Bioenergy

Partnership (GBEP) for bioenergy: „Percentage of land for which soil quality, in particular in terms of soil organic carbon, is maintained or improved out of total land on which bioenergy feedstock is cultivated" (GBEP, 2011). The aim of investigation is evaluation of GHG emissions from usage of perennial grasses, perennial legumes and maize for year round running of biogas plant with electric power of 500 kW.

Materials and Methods

GHG emissions were evaluated for different energy crops usage, including perennial grasses, lupine, galega and maize for biogas production in cogeneration plant with installed electric power of 500 kW during 20-year operational period.

GHG emissions from biomass usage of energy crops for energy production were calculated according to methodology (Cabinet Regulations, 2011):

$$E_B = e_{ec} + e_l + e_p + e_{td} + e_u - e_{csa} - e_{ccs} - c_{cr} - e_{ee} \,, \quad (1)$$

where

- E_B – total emissions from production of bioenergy, gCO_{2eq} MJ^{-1};
- e_{ec} – emissions from growing of biomass (soil tillage, cultivation, fertilization, biomass harvesting), gCO_{2eq} MJ^{-1};
- e_l – emissions from carbon stock changes caused by land use change, gCO_{2eq} MJ^{-1} (for purposes of this investigation $e_l = 0$);
- e_p – emissions from processing (biomass chopping, ensilaging, handling);
- e_{td} – emissions from transportation and distribution, gCO_{2eq} MJ^{-1} (biomass transportation to digester, and digestate transportation and incorporation in the soil);
- e_u – emissions from usage of biofuel, gCO_{2eq} MJ^{-1} (for purposes of this investigation $e_u = 0$);
- e_{sca} – emissions saving from the soil carbon accumulation via improved agricultural management, g_{CO2eq} MJ^{-1};
- e_{ccr} – emissions saving from the carbon dioxide capture and replacement, $gCO_{2eq} \cdot MJ^{-1}$ (e_{ccr} = 0, no CO_2 gases captured or utilized usefully within the scope of this investigation);
- e_{ee} – emissions saving from excess electricity from cogeneration, $gCO_{2eq} \cdot MJ^{-1}$, (for purposes of this investigation $e_{ee} = 0$).

Greenhouse gas emissions from diesel used for biomass treatments during growing or processing were calculated:

$$e_d = \frac{E_D \sum_{j=1}^{m} \sum_{i=1}^{n} D_{ji}}{E_u}, \quad (2)$$

where

- e_d – greenhouse gas (GHG) emissions from diesel used for biomass treatments, $gCO_{2eq;}$
- E_D – GHG emissions per one liter of diesel, E_D = 2 630 gCO_{2eq} l^{-1}, (according to the Cabinet Regulations, 2011);
- n – number of treatments within j^{th} group;
- m – number of groups of treatments with the same diesel consumption in a group;
- D_{ji} – specific diesel consumption per one treatment in j^{th} group, l;
- E_u – useful (exportable) energy produced in cogeneration unit.

Greenhouse gas emissions from soil carbon accumulation via improved agricultural management were calculated:

$$e_{sca} = \frac{0.5\,(OM_{20} - OM_0)\,3.66}{E_u}, \quad (3)$$

where

- 0.5 – coefficient for content of carbon in the soil humus (organic matter);
- OM_{20} – mass of soil organic matter (humus) per 1 ha of soil area after the 20-year period of the energy crops growing, t ha^{-1};
- OM_0 – mass of the soil organic matter per 1 ha of soil area at a start of energy crops growing period, t ha^{-1};
- 3.66 – ratio of molar mass of carbon dioxide (CO_2) to molar mass of carbon (C);
- E_u – useful (exportable) energy obtainable from energy plants area during operation of the biogas cogeneration unit in 20-year period, MJ.

Useful (exportable) energy E_u was calculated:

$$E_u = E_e(1 - k_e) + E_h(1 - k_h), \quad (4)$$

where

- E_e – electric energy produced in the cogeneration unit in 20-year period, MJ;
- k_e – share of electric energy for self-consumption, mostly for mixing of substrate in a fermenter, $K_e = 0.07$;
- E_h – heat energy delivered outside of the cogeneration unit via engine cooling system in 20-year period, MJ;
- k_h – share of heat energy for self-consumption, mostly for heating of the biogas fermenter, $k_h = 0.6$.

Electric energy produced in the cogeneration unit in 20-year period calculates as follows:

$$E_e = \frac{20 \cdot T_O \cdot P_e}{3.6}, \quad (5)$$

where

20 – number of years for biogas plant operation;

T_o – period of time in a year when electric generator is operated at rated power, h yr^{-1};

P_e – rated electric power of the cogeneration unit, kW;

3.6 – energy conversion coefficient (from kWh to MJ).

Heat energy produced in the cogeneration unit in 20-year period calculates as follows:

$$E_h = \frac{K_H \cdot K_{hl} \cdot P_e}{K_E}, \quad (6)$$

where

K_H – share of heat energy from total biogas energy supplied into the cogeneration unit, $K_H = 0.60$;

k_{hl} – coefficient of heat losses in the cogeneration unit, not delivered outside with engine cooling system, e.g. losses with fume gases, losses from cooling of the engine with surrounding air, etc;

K_E – share of electric energy from total biogas energy supplied into cogeneration unit, $K_E = 0.40$.

Greenhouse gas emission saving from biofuels was calculated according to Cabinet Regulations, 2011:

$$SAVING = \frac{E_F - E_B}{E_F}, \quad (7)$$

where

E_F – fossil fuel comparator for cogeneration in Latvia, gCO_{2eq} MJ^{-1};

E_B – total emissions from the biofuel, gCO_{2eq} MJ^{-1}.

Fossil fuel comparator for cogeneration was accepted as 85 gCO_{2eq} MJ^{-1} in Latvia (Cabinet Regulations, 2011).

GHG emissions per 1 ha of energy plant area in one year period calculate as follows:

$$E_{ha} = \frac{E_B}{20 \cdot L_i}, \quad (8)$$

where

L_i – total area of energy plants to provide feedstock for a 500 kW cogeneration plant, ha.

Input data for GHG emissions calculations includes number of treatments, fuel consumption per treatment, dry matter yield and doses of mineral fertilizers for obtaining target yield. Doses of mineral fertilizers were calculated according to proposed dry matter yields (Daiga, 1990, Каюмов, 1986). GHG emissions for production of 1 kg nitrogen (N), phosphorus (P), potassioum (K), lime and pesticides were accepted 5 881 gCO_{2eq} kg^{-1}, 1011 gCO_{2eq} kg^{-1}, 576 gCO_{2eq} kg^{-1}, 129.5 gCO_{2eq} kg^{-1} and 10 971 gCO_{2eq} kg^{-1} respectively.

Results and Discussion

Number of treatments during growing of energy plants depends on plant type, plant longevity, crop rotation and on intensity of cultivation, fertilization, crop protection or harvesting. There no any cultivation, fertilization or crop protection implemented for natural grasslands, due to conservative regime of biodiversity maintenance in those areas. Diesel consumption per treatment of energy crops, average transport distances and number of treatments are provided in Table 1.

Biomass yield from unfertilized natural grasslands varies from 0.9 t ha^{-1} to 3.0 t ha^{-1} (Rūsiņa, 2008), therefore dry mass matter yield of 1.7 t ha^{-1} was accepted for purposes of this investigation, see Table 1. One cut per year is envisaged for harvesting of natural grasses in late summer, when nesting period of birds was over (Rūsiņa, 2008). It is proposed that soil carbon content do not changes during the 20-year period of natural grasses usage for energy production.

Cultivated perennial grasses were fertilized intensively to obtain relatively high average yield of 6.0 t ha^{-1} per year from cultivated grasslands or pastures. Perennial grasses growing intensively results in enrichment of soil with humus (soil organic matter) of 0.60 t ha^{-1} every year while perennial grasses was grown without ploughing. Ploughing of perennial grassland results in soil organic matter losses of 0.7 t ha^{-1} happened when perennial grassland should be ploughed for establishment of the next 4-year growing period of plants (Жуков, 1988).

Perennial legume lupine provides around 7.0 ha^{-1} dry matter yield per year during 4-year growing period. Lupine can be raised on relatively acidic soils and can to provide an enrichment of soil with the humus in amount of 0.42 t·ha^{-1} in years when perennial legume is not ploughed. Soil organic matter losses were presumed around 0.7 t in the year when soil was ploughed for establishment of the next 4-year growing period of lupine (Жуков, 1988).

Legume galega have very long persistence period without reseeding, therefore soil should be cultivated only once for seeding of galega during 20-year harvesting period. Annual yield of fodder galega was varying in range from 9.56 to 11.2 t ha^{-1} (Adamovics, 2008). Average productivity of galega not declines during 20-years period without reseeding of galega.

There no need for galega fertilization with nitrogen (N) fertilizer during whole period of galega growing, excluding the first year when N-fertilizer should be applied for galega establishment (Adamovics, 2008).

Table 1

Number of operations, dry yield biomass, transport distances and growing area of energy plants

Plants	Number of treatments during 20 years period											Transport dist., km	Dry matter yield, $t \cdot ha^{-1}$	Area for 0.5 MW plant
	Ploughing	Min. fertil. spreading	Sowing	Pesticides spraying	Soil tillage	Disc harrowing	Rototilling	Levelling	Harrowing	Harvesting	Rolling			
Natural grasses	0	0	0	0	0	0	0	0	0	20	0	10	1.7	2,219
Perennial grasses	5	35	5	5	5	10	0	5	20	35	5	5	6.0	628
Lupine	5	35	5	5	5	10	0	5	5	35	5	4	7.0	539
Galega	1	20	1	1	1	2	0	1	1	39	1	2.5	9.5	397
Maize	20	40	20	20	20	20	20	20	20	20	0	2	12.0	314
Diesel per treatment, l	22	3.2	3	1.2	7	7	12	10	6	8	2	0.2*		

* Note: diesel consumption for transportation of 1 t in distance of 1 km.

Galega provides soil enrichment with humus in 0.57 $t \cdot ha^{-1}$ every year, excluding the first year when losses of soil humus was 0.7 t ha^{-1}. Green biomass of perennial grasses, lupine or galega was harvested in two cuts in a year without ploughing, and biomass was harvested in one cut in the first year of plants establishment. Natural grasses and maize biomass was harvested only once in a year. Maize provides dry matter yield above 12 t ha^{-1} under climatic conditions in Latvia (Dubrovskis, 2010).

Energy crops area needed for feedstock to biogas cogeneration plant with power of 500 kW plant is inversely proportional to biomass dry matter yield and varies from 2 219 ha for natural grasses to 314 ha for maize, see Table 1.

GHG emissions was calculated according to equations (1-8). Positive GHG emissions from usage of natural grasses were caused by harvesting, transporting, processing, loading of biomass, and from transporting and incorporation of digestate into soil. Negative GHG emissions from natural grasses is related to plant nutrients collecting into digestate utilized for fertilization of other crops (not natural grasslands itself), so replacing the commercial fertilizers, Fig.1.

Perennial grasses fertilization intensively causes the high GHG emissions of 29.1 gCO_{2eq} MJ^{-1} derived from production of nitrogen (N), phosphorus (P), potassioum (K), lime and pesticides. High negative emissions were caused by carbon capture in a soil by perennial grasses within minimal area of 628 ha, see Fig. 1.

Investigated GHG emissions were small for fertilizers production both for lupine or galega thanks

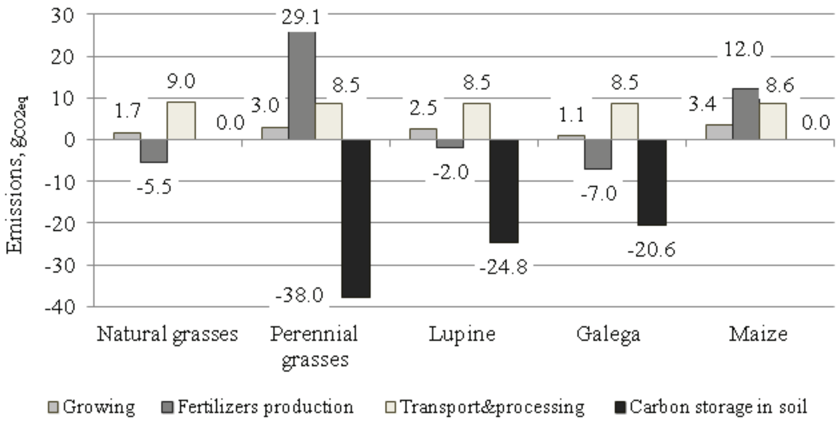

Figure 1. **GHG emissions from energy plants growing, transport&processing and carbon storage in a soil**

to legumes ability to provide self-supply with nitrogen. Nitrogen is the most energy-intensive plant nutrient with emissions of 5 881 gCO_{2eq} per 1 kg commercial fertilizer produced.

Growing of lupine or galega lead to high negative emissions also because of soil enrichment with the humus. Both legumes have deep root system capable to store large quantities of the humus during long growing periods. Galega features excellent longevity at least 20-30 years and have high potential for carbon storage into the soil. Additional dry matter yield can be obtained by seeding of galega in mixtures with other compatible grasses, not reducing the longevity of galega swards (Adamovics, 2008).

Maize growing for energy production do not change soil humus content during 10-years period (Susyan, 2010). Maize can be raised widely for biogas production and have the smallest area for supplying with raw material the biogas cogeneration plant with electric power of 500 KW, see Table 1.

Total GHG emissions released from usage of different plants for biogas energy production are shown in Fig. 2.

Usage of maize lead to hhighest GHG emissions 24 gCO_{2eq} MJ^{-1}, but still providing emission saving 71.8% compare to fossil fuels usage in cogeneration. Lowest negative GHG emissions -18.0 $gCO_{2eq}MJ^{-1}$ have perennial legume galega featuring the best energy plant for renewable energy production and mitigation of climate change. Perennial legume lupine usage results in negative total GHG emissions, see Fig. 2. Lupine can be raised on acidified soils with low soil organic matter content in Eastern part of Latvia widely.

Perennial grasses have small GHG emissions of 2.7 gCO_{2eq} MJ^{-1} and can be grown on cultivated meadows or pastures for energy production while improving the soil organic matter content also. Further improvements will include growing of perennnial grasses in mixtures with legumes for increased productivity and longevity of perennials swards. Utilization of natural grasses from areas with high biodiversity causes GHG emissions in 5.2 gCO_{2eq} MJ^{-1} or provides emission saving 93.9% compare to fossil fuels used in cogeneration.

GHG total emissions per 1 ha area calculated according to formula (8) is shown on Fig. 3.

Emissions were varying from -0.92 tCO_{2eq} ha^{-1} for usage of galega to 1.55 tCO_{2eq} ha^{-1} for usage of maize for biogas production. Further challenge for engineers, agronomists and soil scientists for bioenergy production will be introduction of plants having high yields, high GHG reduction and low or positive impact on soil organic matter content.

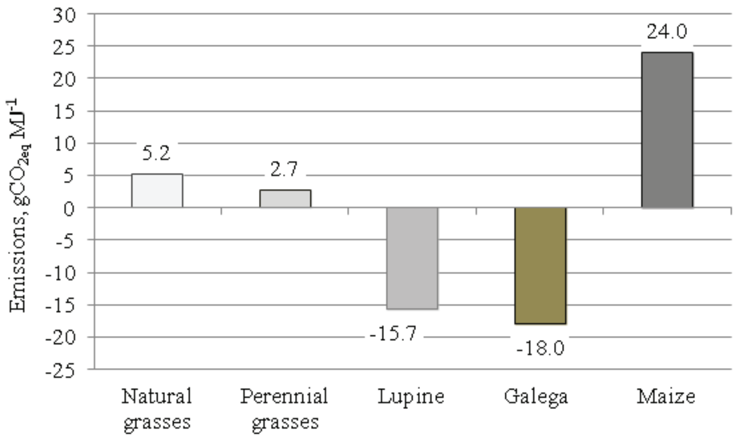

Figure 2. **Total GHG emissions from energy plants usage for energy production**

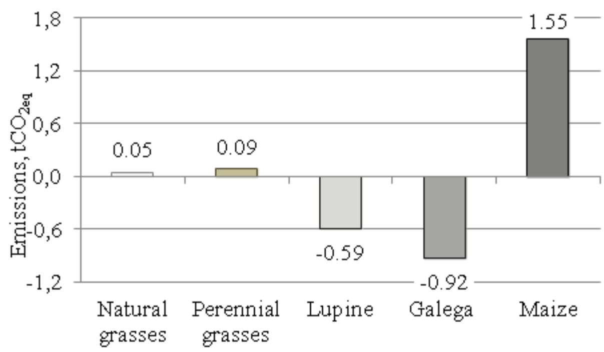

Figure 3. **GHG emissions from energy plants usage for energy production per 1 ha area in year**

Conclusions

1. Natural grasses usage provides low GHG emissions of 5.2 gCO_{2eq} MJ^{-1}, however, the largest area of 2 219 ha is needed to supply feedstock for year round running of biogas plant with electric power of 500 kW.
2. The investigated GHG emissions from usage of intensively fertilized perennial grasses provides very low GHG emissions of 2.7 gCO_{2eq} MJ^{-1} due to plants ability to capture carbon into soil organic matter.
3. Usage of legumes lupine or galega for biogas plant feedstock provides negative GHG emissions, because of the ability of legumes to provide self-supply with nitrogen and to capture carbon into the soil.
4. Highest level of GHG emissions 24 gCO_{2eq} MJ^{-1} was investigated for maize biomass usage for energy production due to intensive soil cultivation and fertilization.
5. GHG emission savings from natural grasses, perennial grasses or maize usage for biogas production is 93.9%, 96.8% or 71.8% respectively compare to usage of fossil fuels in the biogas cogeneration plant with electric power of 500 kW.
6. Legume lupine or galega provides GHG emission savings 118.5% or 121.2% respectively, compare to fossil fuels usage in the cogeneration unit.
7. Lowest negative GHG emissions -18.0 gCO_{2eq} MJ^{-1} was estimated for usage of perennial legume galega featuring the best energy plant for renewable energy production and climate change mitigation.
8. GHG emissions from energy crop area per year were varying from -0.92 tCO_{2eq} ha^{-1} for galega usage to 1.55 tCO_{2eq} ha^{-1} for maize usage for bioenergy production.

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Acknowledgements

This paper has been prepared within the framework of the ESF Project „Attraction of human resources to the research of the renewable energy sources", Contract No. 2009/0225/1DP/1.1.1.2.0/09/APIA/VIAA/129**.**