FORECASTING OF GHG EMISSIONS FROM BIOMASS ENERGY USAGE IN LATVIA

Vilis Dubrovskis, Imants Plūme
Latvia University of Agriculture, Institute of Agricultural Energetics
vilisd@inbox.lv, imants.plume@llu.lv

Abstract. There is a need to forecast greenhouse gases (GHG) emissions from usage of different biomass instead to fossil energy sources (heavy fuel oil, diesel, natural gas) to justify the decisions for heat and power production in Latvia. Help by simplified life cycle estimation method emissions of greenhouse gases was calculated for most feasible biomass technologies for heat, power or biofuels production. The investigated GHG emission savings from usage of wood, straw or straw pellets were 85 %, 93.1 % or 82.9 % compared to heavy fuel oil respectively. 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. GHG emission savings from bioethanol production from grain or biodiesel from rapeseed were 37.5 % or 81.9 % compared to fossil diesel respectively.

Key words: GHG emissions, biomass energy, biogas, bioethanol, biodiesel.

Introduction

Using biomass for heat or power production may not increase greenhouse gases (GHG) emissions directly, however, fossil fuels or electric power are needed for supporting of green technologies, e.g., for soil tillage, fertilisation, sowing, harvesting, biomass pretreatment, biomass utilisation and other operations. The European Community is developing a project of the Directive on sustainable usage of biofuels, where it is appointed, that greenhouse gases (GHG) savings from new biomass-to-biofuels technologies, implemented for substitution of fossil fuels usage, should be at least 35 %. The same criteria should be applied further for biomass usage for renewable energy production, as all the same amount of fossil fuels can be substituted both by biofuels as well as by biomass usage for heat or power energy production. The European Commission proposes that the Member States shall bring into force laws, regulations and administrative provisions necessary to comply with the draft directive on 31 March, 2010 at the latest [2]. The target for share of energy from renewable sources is 40 % in gross final consumption of energy in Latvia in 2020. The climatic conditions, natural resources and available technologies strongly differ from country to country, therefore it is needed to forecast greenhouse gases emissions from usage of different biomass technologies aimed to substitute fossil fuels in every EU country. The aim of the study is evaluation the GHG emissions from available biomass to energy technologies, that can be implemented for substitution of fossil fuels in Latvia.

Methods of evaluation

Evaluation the GHG emissions from available biomass-to-energy technologies covers a specific part of biomass life cycle regarding to direct usage of fossils, e.g., for growing of biomass, harvesting, transportation, pretreatment, processing, conversion in energy (or production of biofuel) and wastes (ashes, digestate) utilization (recycling). Emissions from the manufacture of machinery, equipment and fertilisers are not taken into account.

Greenhouse gas emissions E can be expressed in terms of grams of CO_2 equivalent per MJ of biofuel or energy produced, $gCO_{2eq}\ MJ^{-1}$. The greenhouse gases taken into account shall be CO_2, N_2O, CH_4 and should be valued as follows: CO_2=1, N_2O=296 and CH_4=23. Total greenhouse gas emissions E_B from the production and use of biomass, biofuels and other bioliquids can be calculated as [1]:

$$E_B = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}\ , \tag{1}$$

where e_{ec} – emissions from the extraction or cultivation of raw materials;
e_l – annualised emissions from carbon stock changes caused by land use;
e_p – emissions from processing;
e_{td} – emissions from transport and distribution;
e_u – emissions from the fuel in use;
e_{sca} – emission savings from soil carbon accumulation via improved agricultural management;
e_{ccs} – emission savings from carbon capture and geological storage [2];

e_{ccr} – emission savings from carbon (methane) capture and usage (e.g., CO_2 utilisation in greenhouses, in food industry) [2];
e_{ee} – emission savings from excess electricity from cogeneration.

Emissions from the extraction or cultivation of raw materials e_{ec} can be calculated as:

$$e_{ec} = e_{st} + e_s + e_f + e_{cp} + e_h, \tag{2}$$

where e_{st} – emissions from soil tillage;
e_s – emissions from sowing,
e_f – emissions from fertilisation;
e_{cp} – emissions from crop protection,
e_h – emissions from harvesting, $gCO_{2eq}\ MJ^{-1}$.

Annualised emissions from carbon stock changes caused by land use e_l are included in total greenhouse gas emissions, if the average soil carbon content changes significantly during long-term (e.g. 20-year period) cultivation of energy plants. Emissions from the processing of raw materials e_p can be calculated as:

$$e_p = e_t + e_c + e_{tr} + e_{pc}, \tag{3}$$

where e_t – emissions from transportation of biomass to the processing plant;
e_c – emissions from biomass conditioning (drying, cutting, chopping, shredding, milling, peletizing);
e_{tr} – emissions from biomass treatment (chemical, biological, e.t.c.), $gCO_{2eq}\ MJ^{-1}$.

Emissions from transport and distribution can be calculated as:

$$e_{td} = e_t + e_d + e_{st}, \tag{4}$$

where e_t – emissions from transportation of biomass (biofuels);
e_t – emissions from distribution (packaging, handling, pumping, compressing, etc.) of biomass (biofuels);
e_{st} – emissions from storage (biomass handling, conditioning of microclimate, etc.) of biomass (biofuels), $gCO_{2eq}\ MJ^{-1}$.

Emissions from the biomass (biofuel) in use e_u can be calculated as:

$$e_u = e_{eq} + e_{com} + e_{wu}, \tag{5}$$

where e_{eq} – emissions from the energy unit equipment (transporters, pumps, fanes, and other) operation;
e_{com} – emissions from biomass (biofuels) combustion (conversion into energy),
e_{wu} – emissions from waste (e.g., ashes, digestate) utilisation (landfilling), $gCO_{2eq}\ MJ^{-1}$.

Emissions from the manufacture of machinery and equipment shall not be taken into account [2]. GHG emissions from solid biomass (biofuels) combustion e_{com} arise from methane and nitrogen oxides (biomass is regarded as CO_2 neutral) and can be calculated as:

$$e_{com} = \frac{(23EF_{CH_4} + 296EF_{N_2O})}{\eta_w}, \tag{6}$$

where EFH_4, EFN_2O – mass of methane or nitrogen oxide released per 1 MJ net energy produced respectively, $g\ MJ^{-1}$;
23, 296 – coefficients to value methane or nitrogen oxide as greenhouse gases respectively;
η_w – correction coefficient evaluating the moisture of solid biomass (solid biofuel), if the actual moisture of biomass differs from the default value.

Correction coefficient evaluating the moisture of solid biofuels η_w (for biomass combustion technologies not including heat recovering by flue gases condensation) can be calculated as:

$$\eta_w = \frac{Q_w}{Q_d} , \tag{7}$$

where Q_w – energy wasted for evaporation of water containing 1 kg dry biomass matter, MJ kg^{-1} net energy produced respectively, g MJ^{-1};
Q_d – energy released from combustion of 1 kg dry biomass, MJ kg^{-1}.

Energy wasted for water evaporation from biomass Q_w can be calculated as:

$$Q_w = m_w (c(t_v - t_{wb}) + r)) , \tag{8}$$

where m_w – mass of water evaporated from biomass containing 1 kg dry matter, kg;
c – energy for heating of 1 kg water by 1 °K , c = 0.00419 MJ $kg^{-1}K^{-1}$;
t_v – temperature for water evaporation, t_v = 373°K (100 °C),
t_{wb} – temperature (equal to ambient temperature usually) of wet biomass before combustion, t_{wb} = 383 °K (10 °C),
r – heat energy for evaporation of 1 kg water, r = 2.27 MJ kg^{-1}.

Emissions from mobile machines running on fossil fuel (e.g., diesel, gasoline, LPG) and emissions from equipment powered by electricity can be calculated as:

$$e_F = \frac{\sum_j F_j \, EF_j}{Q_{net}} , \tag{9}$$

where F_j – fuel usually consumed by the machine used for operation, MJ;
EF_j – emission factor for fuel or electricity, gCO_{2eq} MJ^{-1};
j – fuel and electricity type,
Q_{net} – total net energy obtained in the result of implementation of biomass-to-energy technology, MJ.

Energy content (lower calorific value,) for fossil fuel diesel by weight equal to 43 MJ kg^{-1}, or by volume equals to 36 MJ kg^{-1}. Emission factor E_F for fossil fuel j can be calculated as:

$$E_{F_j} = EF_{CO_2 j} + 23EF_{CH_4 j} + 296EF_{N_2Oj} , \tag{10}$$

where $EFCO_{2j}$, $EFCH_4$, EFN_2O – emission factors for carbon dioxide, methane and nitrogen oxide respectively, gCO_{2eq} MJ^{-1}.

Values of emission factors E_{Fj} are calculated by formula (8) and are used for rough evaluation of GHG emissions in Latvia, Table 1.

Emission savings S_E from biomass usage for energy production:

$$S_E = \frac{(E_F - E_B)100}{E_F} , \tag{11}$$

where S_E – emission savings from biomass usage compared to fossil fuel, %;
E_F – fossil fuel (coal, oil, natural gas) comparator, see Table 1, gCO_{2eq} MJ^{-1};
E_B – total emissions from biomass (biofuel) usage for energy production, gCO_{2eq} MJ^{-1}.

Emission savings from soil carbon accumulation e_{sca}, emission savings from carbon capture and geological storage e_{ccs} not included in calculations due to lack of relevant data for Latvia conditions. Emissions from the manufacture of machinery, equipment and mineral fertilizers are not included in calculations. Values of fossil coal, fuel oil and natural gas comparators provided in Latvia have acceptable difference (less than 1 %) compared to the respective values in the EU Directive, apart of the value of fossil diesel comparator having a difference around 11 %, as this value does not include emissions from methane and nitrogen oxides released during combustion of fossil diesel in internal combustion engines.

Table 1

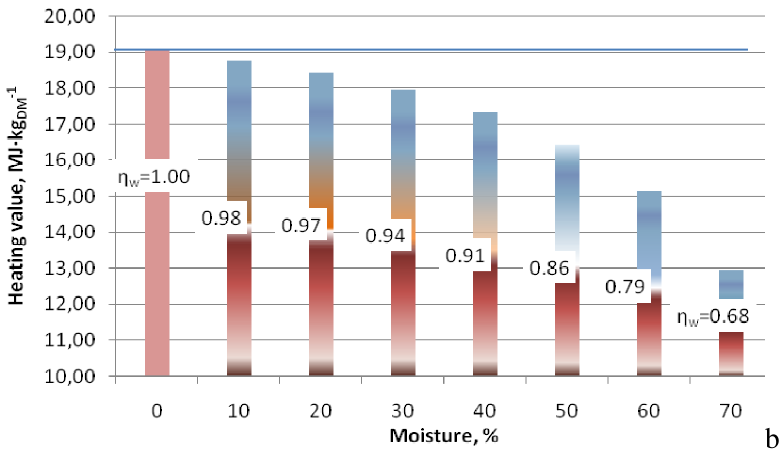
GHG emission factors for fossil fuels, electricity, biofuels and solid biomass usage for energy production, $gCO_{2eq}\,MJ^{-1}$

Fuel Biomass,	Applications	E_F****	E_F	$EFCO_2$	$EFCH_4$	EFN_2O	References
Coal	Energy sector	94.0	94.55	94.08*	0.001	0.0015	[4, TABLE 2.5], *[3]
Residual Fuel Oil	Energy sector	77.0	77.77	77.36*	0.010	0.0006	[4, TABLE 2.5], *[3]
Natural gas	Energy sector	56.1	56.42	56.10*	0.001	0.001	*[3]
Diesel	Mobile of-road machinery	83.4	82.53	74.00*	0.00415	0.0285	[4, TABLE 3.3.1], *[3]
Electricity	Energy sector		100.83**	NA	NA	NA	[5]
Solid Biomass (wood)	Boilers		2.33***	-	0.011	0.007	[4, TABLE 2.6]
Biogasoline, biodiesels	Residential, agriculture		0.41***	-	0.010	0.0006	[4, TABLE 2.5]
Biogas, landfill gas	Residential combustion		0.14***	-	0.005	0.0001	[4, TABLE 2.5]

Notes: *CO_2 emission factor for fully oxidized fossil fuel in Latvia [3]; **GHG emissions from electric energy usage accepted in Latvia ($EF_e = 363\ gCO_{2eq}\ kWh^{-1}$) [5]; ***GHG emissions released in the combustion process of biomass (biofuels), calculated by formula (6); ****Default value of fossil fuel comparator E_F accepted in the EU draft directive.

Results and discussions

Emisions from wood and straw biomass for heat energy production. Technically feasible wood biomass for energy is around 2.48 million t dry biomass annually in Latvia. The amount of straw available for energy production is 0.174 million t biomass annually in Latvia. The average calorific values for dry wood or straw are19.08 or 18.2 MJ kg^{-1} respectively. The average efficiency of combustion unit (boiler) is 0.82 for wood chips and 0.87 for straw bales or straw pellets burning. Average moistures of wood chips, straw or straw pellets are 45 %, 16 % or 9 % respectively. Heating values of wood biomass and correction coefficients evaluating the moisture of biomass are shown in Fig. 1.



b

Fig. 1. **Heating value of wood biomass per 1 kg dry matter and coefficient η_w for correction of heating value in dependence on biomass moisture**

Combustion of solid biomass having less moisture significantly increases the heating value of solid biofuel and decreases GHG emissions accordingly. Fuel is diesel used in machinery for providing of biomass to energy technologies and stationary machines are powered by electricity. Emissions from straw growing, fertilization and harvesting are not included in GHG emissions calculations, due to that straw is considered as waste biomass [1]. Calculated GHG emissions from solid biomass usage for heat energy production in Latvia are presented in Table 2.

Table 2

GHG emissions from biomass technologies for energy or biofuels production in Latvia, $gCO_{2eq}\ MJ^{-1}$

	Emissions	Woodchips	Straw	Straw pellets	Corn for biogas	Biogas from WWW	Biogas from manure	Biogas from wastes	Bioethanol from grain	Biodiesel from rape seed
Cultivation	e_{ec}	8.20	0	0	2.85	0.38	0.6	2.63	5.67	8.32
Processing	e_p	0.23	2.1	9.3	2.91	0.2	0.23	4.84	35.41	5.04
Transportation, distribution	e_u	0.11	0.7	1.4	2.70	0.083	1.27	0	2.46	1.74
Use	e_{sca}	2.88	2.50	2.50	8.92	7.71	7.71	8.73	8.58	9.19
C , CH_4 capture and use	e_{ccr}	0	0	0	0	0	–0.88	0	0	0
Excess electricity from cogeneration	e_{ee}	0	0	0	–1.20	–1.20	–1.20	–1.20	0	0
Sum	$E_{B:}$	11.4	5.3	13.2	16.2	7.2	7.7	15.0	52.1	24.3

Heavy fuel oil is used as fossil comparator for emissions from solid biofuels, as the heavy fuel oil is usually replaced by wood or straw biomass in Latvia, see Fig. 2.

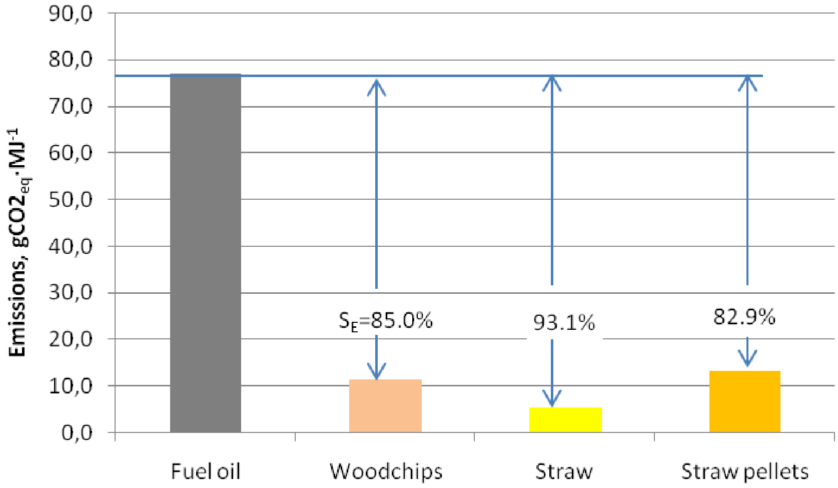


Fig. 2. **Emissions and emission savings from solid biomass usage for heat energy production**

GHG emissions savings from woodchips, straw or straw pellets usage for heat energy production are 83-93 %, if the fossil fuel oil is replaced by biomass combustion for heat production

Emissions from biogas production and utilization. The most perspective is corn usage for biogas production in Latvia due to high dry matter yield. It is proposed that 120 GJ energy can be obtained from 1 ha sown area with corn. Corn biomass is used for biogas production in the biogas plant on the research and training farm of the Latvia University of Agriculture „Vecauce", Dobele region, since 2008. Biogas is produced from wastewater waste plant and from landfilled municipal waste in Riga. There is vast experience on digestion of livestock manure since the eighties in the last century in Latvia. The produced biogas is utilized in cogeneration units including internal combustion set for heat and electric power generation. The dry matter content in cattle manure 12-14 % is accepted for calculations of GHG emissions. GHG emission savings from usage (e_{ccr}) of methane escaping from manure storages in environment is included in calculations, see Table 2 and Fig. 3.

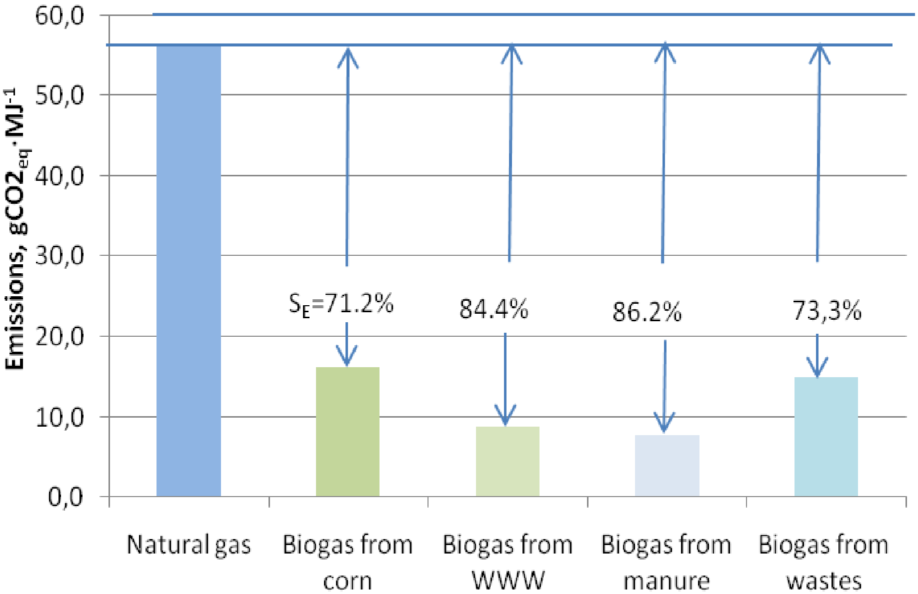


Fig. 3. **Emissions and emission savings from biomass usage for biogas production and for heat and power cogeneration**

GHG emissions savings from biogas production/utilisation from corn, wastewater waste, manure and municipal waste are in the range of 71.2-86.2 % compared to GHG emissions from natural gas usage for cogeneration.

Bioethanol from grain and biodiesel from rapeseed production. There are several plants producing bioethanol from grain (wheat, rye, triticale) or biodiesel from rape seeds in Latvia. Emissions from all operations within the technology life cycle are calculated, including soil tillage, seeding, fertilization, crop protection, harvesting, biomass pretreatment, biomass processing, biofuel processing, biofuel distribution, transportation and by-product utilization. Straw is used as a cheap heat source in the production process of biofuels. Emissions and emission savings from production of liquid biofuels are shown in Fig.4. Emissions from bioethanol production can be lowered, if CO_2 gases released in fermentation process can be utilised in some way, e.g., to enrich the ambient air in greenhouses, for making of dry ice, to carbonate water or for other useful purposes.

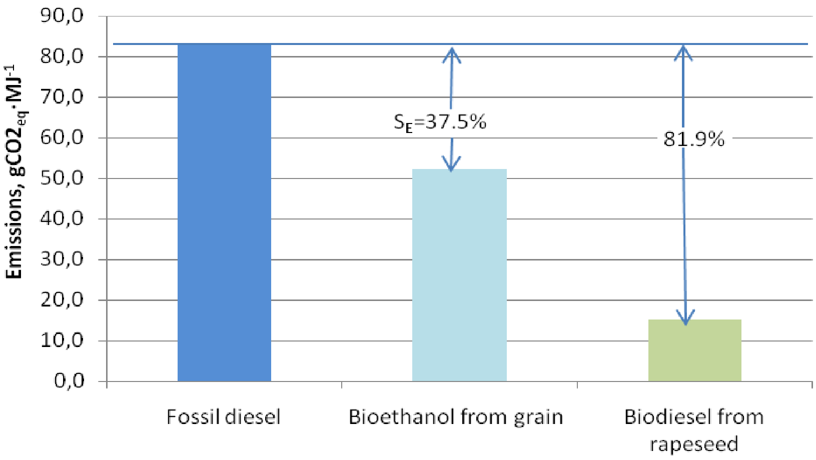


Fig. 4. **Emissions and emission savings from bioethanol and biodiesel production and utilisation**

GHG emission savings from bioethanol production from grain or biodiesel from rapeseed were 37.5 % or 81.9 % compared to fossil diesel usage respectively

Conclusions

1. Values of fossil coal, fuel oil and natural gas comparators provided in Latvia have acceptable difference (less than 1 %) compared to the respective values in the EU Directive, apart of the value of fossil diesel comparator having the difference around 11 %, as this value does not include emissions from methane and nitrogen oxides released during combustion of fossil diesel in internal combustion engines.
2. Combustion of solid biomass having less moisture significantly increases the heating value of solid biofuel and decreases GHG emissions accordingly.
3. The investigated GHG emission savings from usage of wood, straw or straw pellets were 85 %, 93.1 % or 82.9 % compared to heavy fuel oil usage respectively.
4. 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.
5. GHG emission savings from bioethanol production from grain or biodiesel from rapeseed were 37.5 % or 81.9 % compared to fossil diesel usage respectively.

References

1. Draft Directive on the promotion of the use of energy from renewable sources (http://www,abengoabioenergy,es/sites/bioenergy/resources/pdf/acerca_de/informacion_tecnica/en/Promotion_use_energy_from_renewable_sources,pdf),
2. Levine J,, Cofer W,, Cahoon D,, Winstead E, (1995), Biomass burning a driver for global change, Environmental science & Technology, March, 1995 (http://asd-www,larc,nasa,gov/biomass_burn/globe_impact,html),
3. Vidējie lielumi oglekļa dioksīda (CO2) emisiju gaisā aprēķināšanai, (http://www,meteo,lv/upload_file/rokasgramatas/CO2_koef,pdf),
4. 2006 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse Gas Inventories, Volume 2: Energy (http://www,ipcc-nggip,iges,or,jp/public/2006gl/vol2,html).
5. Atjaunojamo energoresursu izmantošanas pamatnostādnes 2006-2013 gadam. Politikas dokumenta stratēģiskais ietekmes uz vidi novērtējums, Vides pārskats,- 2006 (http://www,vidm,gov,lv/files/text/vides_parsk_aer_pamatnost,pdf).