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``Renewable Energy and Energy Efficiency``

Economic and legislative aspects of the renewable energy production

FIBRE CROPS FOR ENERGY PRODUCTION AND ENERGY SAVING

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Abstract
The photosynthesis process generates beside carbon hydrates also complex chemical compounds. The artificial synthesis of such compounds is often impossible or may require high energy input compared with their heating value. In other words, the entropy of energy crops is low compared with that of fossil fuels. This fact is usually neglected in energy analysis of bio fuels resulting in questionable political decisions concerning renewable energy. This paper demonstrates that the energy saving and the GHG mitigation potential of fibre crops may be enhanced using them first used as raw material for commercial products before processing to fuel at the end of their lifetime. For example, reed canary grass may be used for paper production and after recycling the used paper can be processed to insulation material in buildings before thermal use. Such a chain of usage trades off both, the low entropy as raw material for pulp and the heat value of the carbon hydrates. A calculation model is presented to estimate the reduction of CO_2 equivalents of the following two options: Alternative A: Production of reed canary grass + processing to fuel for heating. Alternative B: Production of reed canary grass + processing to paper + recycling of paper + processing to insulation material + installation of insulation material in buildings + recycling of insulation material + processing for heating. The results show that alternative B is outclassing alternative A. Pulp made of reed canary grass for paper and insulation material saves between ten and hundred times or more energy compared with the energy yield of burning. However, fossil fuels render a higher energy return on investment and are for the time being more competitive than both options.
Key words: Fibre crops, energy crops, GHG mitigation, reed canary grass.

Introduction

Energy crops are still considered as an important renewable energy source even though there are many doubts whether they may replace fossil fuels sustainably. The question whether the 'cure is worse than the disease' (Doornbosch and Steenblik, 2007) emerged, when the awareness about environmental impacts of energy crop production especially in the tropics reached public awareness (Fritsche et al., 2006; Mathews, 2007; European Environment Agency, 2007; Fargione, 2008; Searchinger et al. 2009, Young, 2009). A living crop decreases the entropy of matter by the photosynthesis process generating beside carbon hydrates also more complex chemical compounds. Therefore, many crops are used not only for food production but also as raw material for production of commodities (Smeder and Liljedahl, 1996). Energy crops do not only compete with food crops and feed crops, but also with fibre crops for industrial products. This fact is often neglected in energy analysis of energy crops. The GHG mitigation potential of fibre crops may be enhanced using them first as raw material for commodities before processing to fuel at the end of their lifetime. Such a chain of usage trades off both, the low entropy of the fibre and the heating value of the fibre.

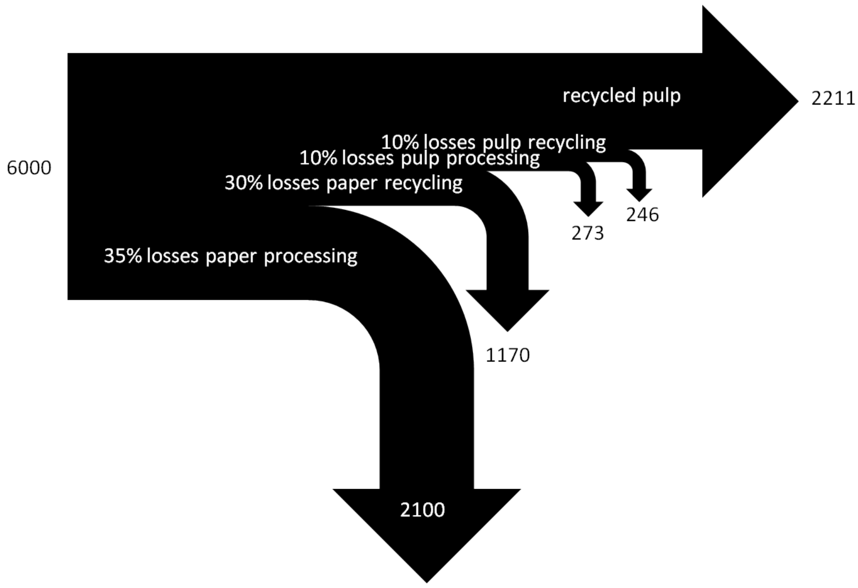
Materials and methods

The calculation model to estimate the reduction of CO_2 equivalents of fibre crops uses reed canary grass (RCG) (*phalaris arundinacea)* as an example. Alternative A includes the production and the processing of RCG to fuel for heating. Hadders and Olsson (1997), Mäkinen et al. (2006), and Lötjönen et al. (2009) describe the process of cultivating and processing and the assumptions made. The heating value h of RCG is about 17 MJ kg^{-1} and the energy gain E_h burning RCG is calculated using equation (1) where Y is the dry matter yield of RCG:

$$E_h = Y \cdot h \quad MJ\ ha^{-1}\ E_h = Y \cdot h \quad MJ\ ha^{-1} \tag{1}$$

Alternative B includes the production of RCG, the processing of RCG to paper, recycling of used paper, processing of recycled paper to pulp as insulation material, installation of pulp in buildings, recycling of pulp, and processing the residues to fuel for heating as in alternative A.

The fibre yield is processed to paper with a mean mass efficiency η_y of 65% (Finell, 2003). The process energy of paper production from birch is 38 MJ kg^{-1} and the CO_2 eq. 1.1 kg kg^{-1} (Gromke and Detzel, 2006). The credit of lower process energy of paper production from RCG compared with pulp from wood is neglected. The recycling efficiency η_p of used paper is about 70% (Finnish Forest Industries Yearbook, 2007) and the mass efficiency η_{pr} of processing used paper to pulp is estimated to 90%. The process energy of pulp production is 3.25 MJ kg^{-1} and the CO_2 emissions about 0.2 kg kg^{-1} (Rakennustieto, 2000). The heating value of the mass losses for processing may compensate the energy demand for installation of the pulp as insulation



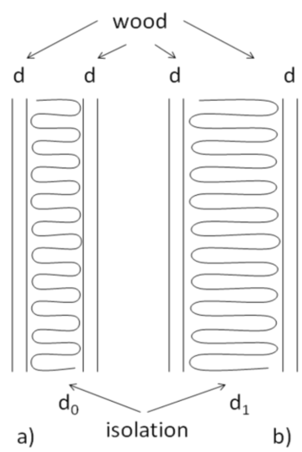
Source: yield 6000 kg ha^{-1}: estimated, 35% losses paper processing: Finell (2003), 30% losses paper recycling: Finnish Forest Industries Yearbook (2007), 10% losses pulp processing: estimated, 10% losses pulp recycling: estimated.

Figure 1. **Mass flow of alternative B. All mass figures in kg ha^{-1}**

material in buildings, recycling, and transport. Figure 1 shows the mass flow of alternative B.

To calculate the saved energy using the pulp in buildings for improvement of heat insulation, the model wall or ceiling construction described in Figure 2 is used. Figure 2a shows a simple wall element made of two d = 0.022 m thick wood walls filled with pulp insulation. The U-value of the wall insulation declines widening the insulation thickness increment $\Delta d = d_1 - d_0$ in fig 2b. Therefore, the saved energy depends on two variables, the original insulation, and the improved insulation.

The installation density ρ of the pulp is 30 kg m^{-3} and determines together with the thickness of insulation the amount of square meters of the model wall or ceiling to be insulated with the fibre yield of one hectare. The thermal conductivity of wood λ_w is 0.14 and of pulp λ_p 0.041 W K^{-1} m^{-1}. The external surface resistance R_e = 0.13 m^2 K W^{-1} and the internal surface resistance R_i = 0.04 m^2 K W^{-1} for the horizontal heat flow through walls (EN ISO 6946, 1997). The mean temperature in middle Finland (Jyväskylä) T_m is 0.87°C during the heating period of 273 days from September to May (Finnish Meteorological Institute, 2011). The room temperature T_r is +20°C. The lifetime of the insulation v is estimated to 50 years. The saved energy E_S during the lifetime of the wall is then calculated with following equations:



Source: made by the author

Figure 2. **Model wall construction, a) original insulation, b) improved insulation. d_0 = original insulation thickness, d_1 = thickness of wider insulation, d = thickness of the inner and outer wood wall**

$$E_S = (U_0 - U_1) \cdot Y \cdot \eta_y \cdot \eta_y \cdot \eta_r \cdot (\rho \cdot \Delta d)^{-1} \cdot (T_r - T_m) \cdot d \cdot v \cdot 0.0864 \quad MJ\ ha^{-1} \tag{2}$$

$$U_0 = \left(R_i + 2 \cdot d_w \cdot \lambda_w^{-1} + d_0 \cdot \lambda_p^{-1} + R_a\right)^{-1} \quad W\ K^{-1} m^2 \tag{3}$$

$$U_1 = \left(R_i + 2 \cdot d_w \cdot \lambda_w^{-1} + [\![(d]\!]_0 + \Delta d) \cdot \lambda_p^{-1} + R_a\right)^{-1} \quad W\ K^{-1} m^2 \tag{4}$$

At the end of the lifetime, the pulp can be used as fuel for burning assuming a recycling efficiency of 90%.

The ratio of E_s/E_h shows, how much more energy can be saved using the pulp for insulation compared with burning RCG. The heating value of pulp may be similar to that of RCG and burning this waste may additionally improve the energy balance. However, usually boron is added to the pulp as flame retardant compound, which decreases the lower heating value.

The energy return on investment (EROI) is calculated from the energy input E_{in} and output E_{out} using the following equation:

$$EROI = \frac{E_{out} - E_{in}}{E_{in}} \tag{5}$$

The CO_2 equivalent emission mitigation from the saved energy depends mainly on the substituted fuel mix. Any conversion factor for energy conversion into CO_2 equivalents may be used. It will not change the quality of the results.

Results and discussion

The energy input for RCG production is 0.078 GJ GJ^{-1} and the CO_2 eq. balance is 0.015 kg CO_2 MJ^1 (Lötjönen et al. 2009 after Mäkinen et al. 2006). Thus the *EROI* for heat production from RCG is 11.8 MJ MJ^{-1} assuming a dry matter yield of 6 Mg ha^1 corresponding to a gross energy yield of 102 GJ ha^1. However, this calculation takes into consideration only 8 GJ ha^1 for fuels and fertilisers as energy input of RCG production.

$$EROI = \frac{102\ MJ\ ha^{-1} - 8\ MJ\ ha^{-1}}{8\ MJ\ ha^{-1}} = 11.75\ MJ^{-MJ} \tag{6}$$

The proportion of indirect energy input reached in 1999 in Danish agriculture more than 70% (Rydberg and Haden, 2006) of the total energy input. Given ⅓ of the total indirect energy input into agricultural production is used up by crop production, indirect energy input for RCG may reach 6.2 GJ/ha. Thus, a realistic value of the *EROI* is about 6.2 MJ MJ^{-1}. The realistic net energy gain is than about 88 GJ ha^1.

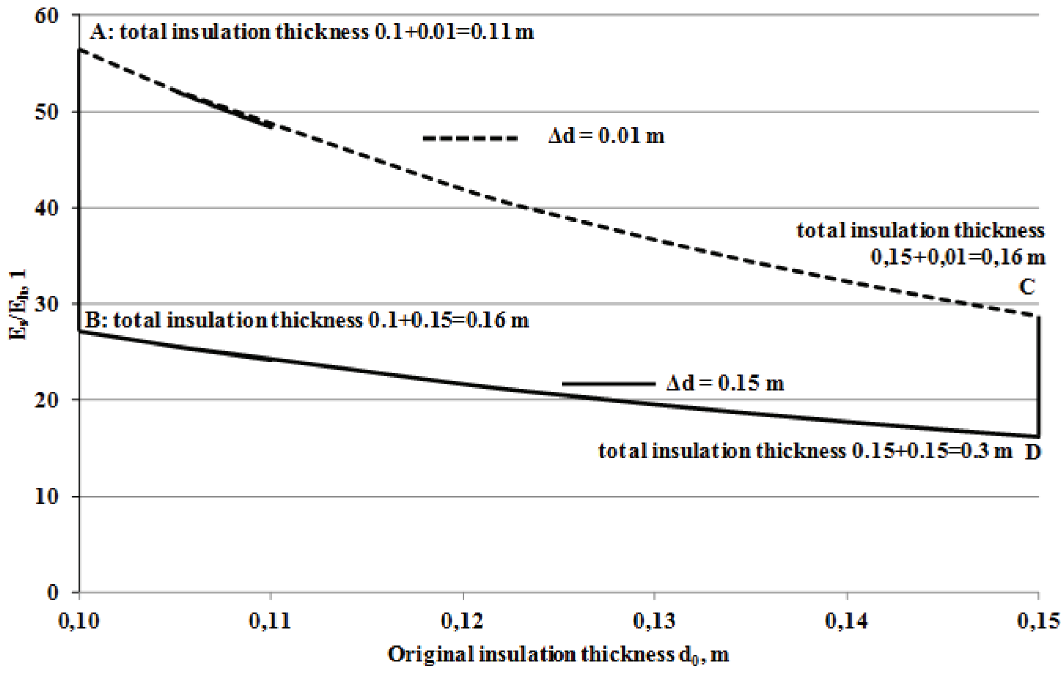
$$EROI = \frac{102\ MJ\ ha^{-1} - (8 + 6.2) MJ\ ha^{-1}}{(8 + 6.2) MJ\ ha^{-1}} = 6.18\ MJ^{-MJ} \tag{7}$$

If RCG would be used for biogas production, the energy gain may reach the half compared with burning. Although biogas may replace fossil fuels for combustion engines, the *EROI* would be too low to become a competitive alternative to fossil fuels. The *EROI* of fossil fuels ranges after Pimentel (2008) between 10 and 20.

The saved energy of alternative B is in equation (2) expressed as a function of the original insulation thickness and the insulation thickness increment Δd as parameter. The original insulation thickness d_0 may e.g. range between 0.1 and 0.15 m. Then the area enclosed by the points ABCD in Figure 3 embraces the energy saving potential widening the insulation thickness by 0.01 (dotted line) to 0.15 m (solid line) resulting in a final insulation thickness between 0.11 and 0.3 m. It is evident, that the energy saving efficiency of widening insulation thickness is lower when the original insulation d_0 is wider and vice versa.

Table 1 shows the result of the energy saving calculations at point D. The calculation of CO_2 equivalents savings at point D is given in Table 2. Widening the pulp insulation thickness d_0 of a well-insulated wall or ceiling from 0.15 m to 0.3 m saves 1,521 GJ ha^1. This is about sixteen times more energy than the energy gain of alternative A. Widening the pulp insulation thickness d_0 of a fair-insulated wall or ceiling from 0.1 m to 0.11 m saves even 5,310 GJ ha^1.

This is about fifty six times more energy than the energy gain of alternative A. In other words, the net energy gain of burning the yield of 1 ha RCG pays back within three years at point D and within one year only at point A. One may object that these considerable amounts of saved energy are accumulated over a period of 50 years.



Source: made by the author using equations (1) to (4)

Figure 3. **Ratio between saved energy E_s by insulation improvement and heat gain E_h of burning RCG as a function of the original insulation thickness d_0 and the insulation thickness increment Δd.**

Table 1

Calculation of the energy saving potential at point D of Figure 3

Process	Energy	Unit
Alternative A		
Gross energy yield of heat production from RCG: $6000\ kg\ ha^{-1} \cdot 17\ MJ\ kg^{-1}$	102,000	MJ ha^{-1}
Energy input of RCG production: $0.078\ GJ\ GJ^{-1} \cdot 102{,}000\ MJ\ ha^{-1}$	-7,956	MJ ha^{-1}
Net energy gain burning RCG	**94,044**	**MJ ha^{-1}**
Alternative B		
Energy input of RCG production	-7,956	MJ ha^{-1}
Energy input of paper production: $38\ MJ\ kg^{-1} \cdot 3{,}900\ kg\ ha^{-1}$	-148,200	MJ ha^{-1}
Energy gain from paper production waste: $6{,}000 - 3{,}900 = 2100\ kg\ ha^{-1} \cdot 17\ MJ\ kg^{-1}$	35,700	MJ ha^{-1}
Energy input of pulp production from recycled paper: $2{,}730\ kg\ ha^{-1} \cdot 3.25\ MJ\ kg^{-1}$	-8,873	MJ ha^{-1}
Energy gain from pulp production waste: $3{,}900 - 2{,}730 = 1{,}170\ kg\ ha^{-1} \cdot 17\ MJ\ kg^{-1}$	19,890	MJ ha^{-1}
Total energy input insulation production	**-109,439**	**MJ ha^{-1}**
Net energy gain by saving energy from additional insulation at point D of Figure 3	**1,521,256**	**MJ ha^{-1}**
EROI using RCG as insulation material at point D of Figure 3	14	MJ MJ^{-1}

Source: figures presented in chapter materials and methods

Table 2

Calculation of GHG mitigation potential at point D of Figure 3

Process and substitution alternatives	kg CO_2eq. ha^{-1}
Emissions from RCG production: $0.015\ kg\ CO_2eq.MJ^{-1} \cdot 102{,}000\ MJ\ ha^{-1}$	1,530
Emissions from paper production: $1.1\ kg\ CO_2eq.kg^{-1} \cdot 3{,}900\ kg\ ha^{-1}$	4,290
Emissions from pulp production of recycled paper: $0.2\ kg\ CO_2eq.kg^{-1} \cdot 2{,}730\ kg\ ha^{-1}$	491
Total emissions	**6,311**
Mitigation from saved light fuel oil: $1{,}521{,}256\ MJ\ ha^{-1} \cdot 86\ g\ CO_2eq.MJ^{-1}$	125,108
Mitigation from saved natural gas: $1{,}521{,}256\ MJ\ ha^{-1} \cdot 69\ g\ CO_2eq.MJ^{-1}$	98, 064
Mitigation from saved district heating: $1{,}521{,}256\ MJ\ ha^{-1} \cdot 61\ g\ CO_2eq.MJ^{-1}$	86,654
Mitigation from saved electric power: $1{,}521{,}256\ MJ\ ha^{-1} \cdot 190\ g\ CO_2eq.MJ^{-1}$	282,305

Source: CO_2eq of RCG: Lötjönen et al. (2009), CO_2eq of paper: Gromke and Detzel (2006), CO_2eq of pulp: Rakennustieto (2000), CO_2eq of fuels: Bremer Energie-Konsens GmbH (2006)

However, during the lifetime of 50 years, every year the harvest of RCG can be processed to paper and pulp. If the process of paper production is excluded and the yield of RCG is immediately processed to pulp for insulation purposes, the energy saving increases even more. It is evident that this energy saving figures are realistic in new construction buildings or under circumstances where the insulation improvement of existing buildings does not require additional demolition and construction work, e.g. improving the insulation thickness of a ceiling by blowing the pulp under the roof.

The *EROI* of alternative B reaches the magnitude of fossil fuels. However, if the indirect energy demand for RCG production, paper, and pulp production is taken into consideration, the *EROI* will drop below 10. Another aspect of energy saving and GHG mitigation is the replacement of mineral insulation material by pulp. The energy demand of rock wool production is about five times higher compared with pulp production from recycled paper (Rockwool International A/S, 2009). Thus, the 2,730 kg pulp ha^{-1} from recycled newspaper may save about 46 GJ needed to produce an equivalent quantity of rock wool resulting in a net energy gain of 37 GJ/ha.

Conclusions

The calculation example shows clearly that fibre crops should first be used as feedstock for industrial commodities before the residues are converted to energy at the end of the lifetime. Producing a table from a tree and burning the residues and the table at the end of its lifetime renders the same energy gain as using the tree for firewood only. Because of the second law of thermodynamics, decrease of entropy without energy input is impossible. Only the photosynthesis process, powered by sun energy, guaranties low entropy products for humans and animals. Thus, fibre crops processed and used as insulation material render an excellent example of high energy efficiency. The reason, why energy crops are recently used for fuels only, may be explained by agricultural subsidy policies, violation of basic thermodynamic laws, and neglecting both indirect energy input and external cost of energy crop production. Anyway, the energy return on investment of fossil fuels is still higher and therefore CO_2 mitigation using renewable energy sources is more expensive for the time being.

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INDUSTRIAL HEMP – A PROMISING SOURCE FOR BIOMASS PRODUCTION

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Abstract
The biometrical indices of eight hemp (*Cannabis sativa* L.) cultivars ('Beniko', 'Bialobrezskie', 'Epsilon 68', 'Fedora 17', 'Felina 32', 'Futura 75', 'Santhica 27' and 'USO 31') have been investigated at the Upytė Research Station of LRCAF in 2010-2011. The results of investigation show that this plant is a promising source of biomass, accounting for 38.7 t ha^{-1} of green biomass, and 13.1 t ha^{-1} of absolutely dry biomass. Results of investigation of biomass potential of 8 industrial hemp varieties are presented.
Key words: hemp, biomass production, biomass yield.

Introduction

Hemp has been cultivated over a period of many centuries in almost every European country. Many kinds of products could be produced from this useful plant: textiles for apparel and cottonized hemp, mats for thermal insulation in the construction industry, specialty pulp and paper for technical applications, press-moulded interior panels for the automotive industry, geotextiles for erosion control, needle-punched carpeting, hurds used as animal bedding, seed and oil for food sector, natural bodycare products, gamma linolenic acid in the cosmetics and pharmaceutical industries, natural THC-based therapeutic drugs, etc. (Bocsa et al., 1998).

Nowadays hemp has become very important as a crop for biomass production. Energy production in the form of solid fuel from the whole hemp stem is a relatively new use for the crop (Energy ..., 2009).

Hemp biomass could be used for energy purposes in different ways: by burning (co-fired with coal to reduce emissions and offset a fraction of coal use; burned to produce electricity; pelletized to heat structures; made or cut into logs for heating; gasification), as oils (vegetable, seed and plant oil used "as-is" in diesel engines; biodiesel – vegetable oil converted by chemical reaction; converted into high-quality non-toxic lubricants), by conversion of cellulose to alcohol (Castleman, 2006; Prade, 2011).

The aim of our research was the evaluation of the biomass potential of some industrial hemp varieties to be late on suggested to grow in Lithuania.

Materials and Methods

Research was carried out at the Lithuanian Research Centre for Agriculture and Forestry Upytė Experimental Station on a *Eutri-Endohypogleyic Cambisol*, *CMg-n-w-eu* (Buivydaitė et al., 2001) in 2010–2011. The content of available phosphorus in the soil plough layer was 137–245 mg kg^{-1}, content of available potassium – 129–152 mg kg^{-1} (determined in A-L extraction), pH_{KCl} level – 6.7-7.7 (potentiometrically), humus content – 1.89–2.33 % (by Hereus apparatus). In 2011 soil properties showed rather lower values.

In the field rotation, hemp followed winter wheat. Before sowing, 200 kg of complex fertilizers $N_7P_{19}K_{29}S_3$ and 200 kg of complex fertilizers $N_{16}P_{16}K_{16}$ were applied in 2010 and 300 kg+300 kg of the same fertilisers in 2011. Hemp was sown (seed rate 40-50 kg ha^{-1}) by sowing-machine SLN-1.6 at the beginning of May in the plots of 10 m^2, triplicate. Randomised plot design was used. Protective plots of the same size were sown on both sides of the trial.

All tested cultivars are monoecious (male and female flowers are present on the same plant). The cultivars 'Beniko' and 'Bialobrzeskie' are considered semi-early in Poland, the country of their origin. The cultivar 'Epsilon 68' is late-ripening in France, the cultivar 'Felina 32' (both are of French origin) – semi-late in France, the cultivar 'Futura 75' – late-maturing in France, and the cultivar USO 31 (of Ukrainian origin) is known as very early in France.

Hemp crop density was assessed after full crop emergence and at harvesting.

No pesticides (insecticides, herbicides, desiccants) were used.

Hemp was harvested by a trimmer (leaving the stubble of 5-8 cm) when the first matured seed appeared (it was on September 9th (for the cultivar USO 31) and 4th of October (for the rest part of cultivars) in 2010 and on the 13th of September (for the cultivar USO 31) and the 22-23rd of September (for the other cultivars tested) in 2011.

The yield of green and dry biomass (over-ground mass) was evaluated at hemp harvesting time. The main task of the research presented here was to evaluate biomass potential of different varieties, to discus some parameters influencing on biomass production.

For calculations and statistical evaluation, we used the statistical software developed at the Lithuanian Institute of Agriculture of the Lithuanian Research Centre for Agriculture and Forestry (Tarakanovas et al., 2003).

Meteorological conditions (Table 1) during the experimental years were diverse, but both growing

Table 1

Meteorological conditions during hemp growing season

Month	Ten-day period	Mean air temperature ºC			Rainfall mm		
		2010	2011	Long-term average	2010	2011	Long-term average
May	I	12.6	11.2	11.0	25.0	1.0	16.0
	II	15.6	12.6	12.6	18.0	18.7	16.0
	III	15.1	14.9	13.5	20.5	7.0	18.0
	Average	**14.4**	**12.9**	**12.4**	**63.5**	**26.7**	**50.0**
June	I	18.4	16.5	14.4	11.0	11.0	22.0
	II	15.9	18.7	15.3	49.5	15.0	23.0
	III	**17.8**	**19.6**	16.2	21.0	13.5	24.0
	Average	17.4	18.3	**15.3**	**81.5**	**39.5**	**69.0**
July	I	21.3	22.6	17.2	28.0	37.0	25.0
	II	24.5	22.6	18.0	17.0	28.0	25.0
	III	**23.9**	**21.4**	18.0	72.0	69.5	26.0
	Average	23.2	22.2	**17.7**	**117.0**	**134.5**	**76.0**
August	I	23.9	16.7	17.2	11.0	29.5	28.0
	II	23.3	18.2	16.1	30.5	36.5	29.0
	III	15.4	17.0	15.0	34.5	29.0	28.0
	Average	**20.9**	**17.3**	**16.1**	**76.0**	**95.0**	**85.0**
September	I	12.5	14.1	–	8.0	21.0	–
	II	11.3	12.6	–	20.0	28.0	–
	III	14.7	13.6	–	27.0	1.0	–
	Average	**12.8**	**13.4**	–	**55.0**	**50.0**	–

Source: Upytė Experimental Station, 2010, 2011.

seasons were abundant in rainfall which differed only at hemp growing stages.

In 2010, the period for hemp seed emergence was favourable, but later on a lack of precipitation occurred (1st ten-day period of June). Then conditions for hemp growing and developing were favourable (2nd and 3rd ten-day periods of June). The weather in July was warm, and the rainfall was sufficient for hemp growing. The weather in August was warm and rainy (except the 1st ten-day period), September was cooler and dryer.

In 2011, the period for hemp seed emergence was again favourable. Later on the weather was warm, but the lack of precipitation appeared in June. Warm weather and especially abundant precipitation in July and August delayed and prolonged the hemp flowering period, delayed the seed ripening period. In September, it was still warm and rainy.

Thermal and irrigation conditions during the growing season could be described by one of the most informative agrometeorological indicators – G. Selianinov's hydrothermal coefficient (1) (Bukantis, 1998):

$$HTK = \frac{\Sigma p}{0.1\Sigma t} \qquad (1)$$

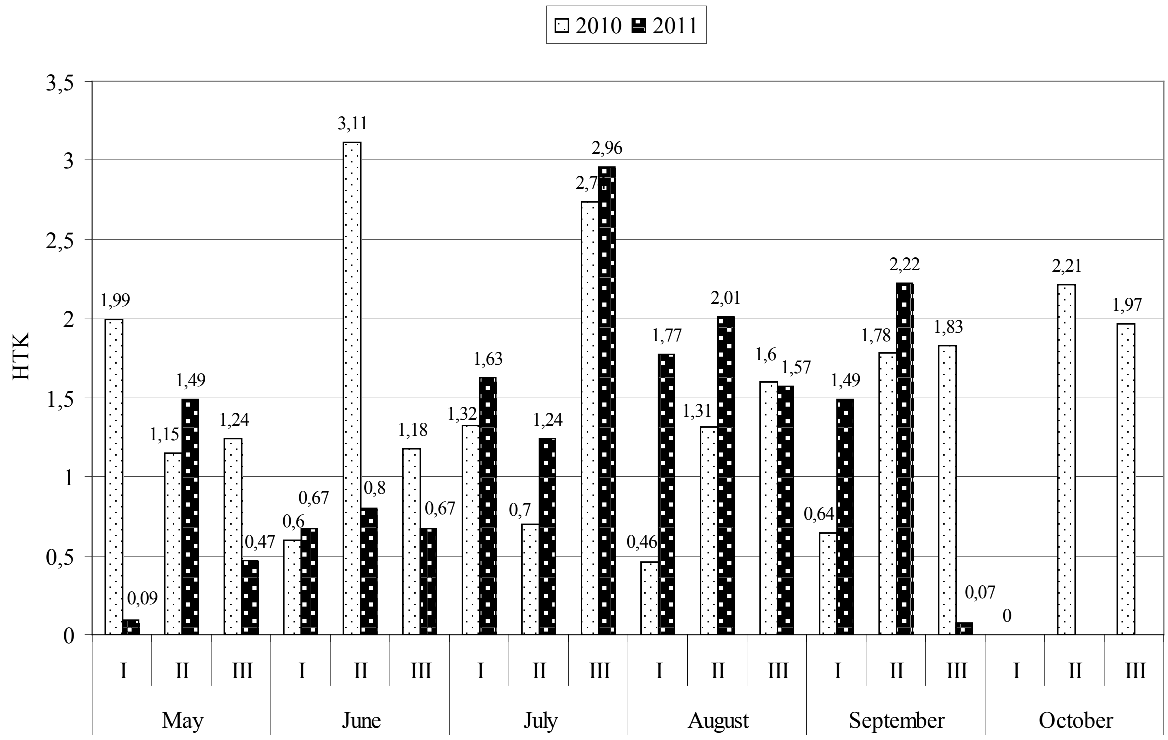
where:

- Σp – total precipitation (mm) sum during the given period, the temperature of which is above 10 ˚C;
- Σt – total sum of active temperatures (˚C) of the same period.

If HTK>1.6 – the irrigation is excessive, HTK=1...1.5 – optimal irrigation, HTK=0.9...0.8 – weak drought, HTK=07...0.6 – moderate drought, HTK=05...0.4 – strong drought, HTK<0.4 – very strong drought.

According to the data presented in Figure 1, we can see that in 2010 it was enough wet for hemp seed germination (May month). In the first ten-day period it was drought, but on the 2nd ten-day period the irrigation was excessive, then it was close to the normal for 2 (2nd and 3rd) ten-day periods. The abundant precipitation in July 3rd ten-day period and in September (2nd, 3rd ten-day periods) allowed hemp plants to thrive, but led to a long vegetation period, a long flowering period, late seed ripening. Hemp was harvested only in October.

In 2011 the hydrothermal coefficient was favourable for seed germination. Later on (in June) it was moderate drought in the field, but the rest part of



Source: Upytė Experimental Station, 2010, 2011.

Figure 1. **Hydrothermal coefficient during the hemp vegetation period**

hemp vegetation period had a plenty of precipitation. The irrigation was excessive in July 1st ten-day period, July 2nd, August 1st, 2nd, September 2nd ten-day period. Of course, abundance of precipitation prolonged the hemp flowering, vegetation period.

Results and Discussion

In 2010, the established crop density was between 150–431 plants m^{-2}, while in 2011 it was between 153–199 plants m^{-2} (Table 2). In 2010, the cultivar 'Bialobrzeskie' showed bad results of seed germination determined in the laboratory before sowing, so the seed rate was calculated rather higher than that for other cultivars. But in the field, the cultivar 'Bialobrzeskie' emerged perfectly and showed very high crop density – 431 plants m^{-2} after full emergence and 323 plants m^{-2} at harvesting while the lowest crop density was found in the plots of cultivars 'USO 31' (150 plants m^{-2} after full emergence and 115 plants m^{-2} at harvesting), 'Futura 75' (171 and 131, respectively), 'Beniko' (172 and 139, respectively) (the differences were significant). In 2011 the lowest crop density after full emergence was recorded for the plots of cultivars 'Beniko' (153 plants m^{-2}) and the highest – in the plots of 'Futura 75' (199 plants m^{-2}). At hemp harvesting time, the lowest crop density was found in the plots of 'Epsilon 68' (111 plants m^{-2}) and the highest – in the plots of 'USO 31' (146 plants m^{-2}), but the differences were not significant. We guess that crop density at the beginning of the growing season was different between cultivars because of the difference in 1000 seed weight.

On average, crop density after full emergence was close to 173 and 224 (in 2011 and in 2010) plants m^{-2} and at harvesting time it was close to 134 and 184 plants m^{-2} (in 2011 and in 2010), i.e., crop density decreased during the crop vegetation period. „Self-shading" or "self-thinning" in hemp crop, or in other words – reduction of crop density, was mentioned by a parade of authors (Amaducci et al., 2002, Jankauskienė et al., 2010, Mediavilla et al., 1998, Struik et al., 2000, van der Werf et al., 1995 a and b), etc.

In our trials, the reduction of hemp crop density was on average 40 plants m^{-2} in both years. Significantly higher reduction was recorded in 2010 for the cultivar 'Bialobrzeskie' (109 plants m^{-2}) and for the cultivar 'Futura 75' (61 plants m^{-2}) in 2011. We tried to express the reduction in percents also, hoping to find some relationship between crop density and reduction value. Some authors report that self-thinning showed negligible plant loss at low density (30-90 plants m^{-2}), while at high density (180 and 270 plants m^{-2}) 50 % and 60 % of the initial stand was lost (Amaducci et al., 2002). In our trials, the reduction of crop density was between 8.8-24.6 % in 2010 and between 13.6-33.7 % in 2011. The average data show that in our trials the percentage reduction of crop density was different in both years and was higher at lower crop density. Nevertheless, in several cases, the percentage reduction of crop density was highest at the highest crop density (as for cultivar 'Bialobrzeskie' in 2010).

We found some correlation between crop density after full emergence and reduction, expressed

Table 2.

Hemp crop density after full emergence, at harvesting, and reduction

Cultivar	Crop density after full emergence, plants m^{-2}	Crop density at harvesting, plants m^{-2}	Reduction,	
			plants m^{-2}	%
2010				
'Beniko'	172*	139*	33	18.9
'Bialobrzeskie'	431*	323*	109*	24.6
'Epsilon 68'	209	179	29	14.5
'Fedora 17'	207	174	33	16.2
'Felina 32'	214	195	19	8.8
'Futura 75'	171*	131*	39	22.7
'Santhica 27'	241	215*	26	10.8
'USO 31'	150*	115*	35	22.0
Average	224.2	183.9	40.3	17.34
LSD_{05}	35.11	27.52	29.07	10.58
2011				
'Beniko'	153	133	20.7	13.6
'Bialobrzeskie'	183	131	51.3	27.5
'Epsilon 68'	169	111	58.0	33.7*
'Fedora 17'	175	135	39.3	22.5
'Felina 32'	163	135	28.0	17.0
'Futura 75'	199	138	61.3*	30.3
'Santhica 27'	169	141	27.3	16.5
'USO 31'	194	146	48.0	24.6
Average	173.1	133.8	39.3	22.1
LSD_{05}	30.99	26.16	19.54	8.87

Source: Upytė Experimental Station, 2010, 2011.
* significant differences at 95 % probability level.

in plants m^{-2}. In 2010 it could be described by equation 2, determination coefficient 0.57, and in 2011 – by equation 3, determination coefficient 0.46:

$$y = -24.14 + 0.2875x \quad (2)$$
$$y = -46.80 + 0.5144x \quad (3)$$

where:

y – reduction of crop density, plants m^{-2};

x – crop density after full emergence, plants m^{-2};

Nevertheless, the 8.8-33.7 % of fully emerged plants died, but the rest of the survived plants produced sufficiently high biomass yield.

In 2010, hemp produced high amount (on average 32.3 t ha^{-1}) of green over-ground mass (stalks, leaves and panicles) (Table 3). Only plants of 'Futura 75' produced significantly higher amount of green mass (38.7 t ha^{-1}) than the other cultivars tested. The biomass of cultivar 'Fedora 17' was significantly lower (only 26.7 t ha^{-1}). In 2011, the green biomass yield was a little bit lower (on average 29.4 t ha^{-1}) than that in 2010 (on average 32.3 t ha^{-1}). The highest amount of green biomass was produced again by plants of cultivar 'Futura 75' (33.2 t ha^{-1}), but the differences between the cultivars were not significant. The lowest productivity of the tested cultivars was given again by 'Fedora 17' (23.2 t ha^{-1}).

The yield of absolutely dry hemp biomass was calculated according to the data of hemp green biomass and its moisture content at harvesting. The moisture content of green biomass was higher in 2010 (on average 67.4 %), while in 2011 it was 60.8 %. The significantly lowest moisture content in 2010 was found in the plants of 'Santhica 27' (64.6%). In 2010, the differences in moisture content between cultivars were not significant.

In 2010, plants of the tested hemp cultivars produced on average 10.5 t ha^{-1} of dry over-ground biomass, and 11.5 t ha^{-1} in 2011. In some our trials earlier, the average dry mass yield of 14.6 t ha^{-1} for the cultivar 'Beniko' was recorded (Jankauskiene et al., 2009). The average dry mass yield 19.8 t ha^{-1} was recorded

Table 3.

Green over-ground biomass yield, its moisture content, and dry biomass yield of hemp crop

Cultivar	Green biomass kg ha^{-1}	Moisture content in green biomass %	Absolutely dry mass kg ha^{-1}
2010			
‘Beniko’	31 538	69.1	9 732
‘Bialobrzeskie’	34 359	66.3	11 607
‘Epsilon 68’	35 897	68.6	11 277
‘Fedora 17’	26 667*	66.8	8 883
‘Felina 32’	28 718	66.8	9 565
‘Futura 75’	38 718*	69.4	11 838
‘Santhica 27’	28 974	64.6*	10 312
‘USO 31’	33 333	68.2	10 616
Average	32 275.6	67.45	10 478.7
LSD_{05}	5 606.53	2.804	2 225 62
2011			
‘Beniko’	33 067	60.4	13 124
‘Bialobrzeskie’	28 356	59.8	11 358
‘Epsilon 68’	28 533	62.2	10 626
‘Fedora 17’	23 156*	63.3	8 456*
‘Felina 32’	29 667	60.1	11 844
‘Futura 75’	33 244	63.1	12 288
‘Santhica 27’	29 289	59.3	11 937
‘USO 31’	25 644	62.3	9 676
Average	29 348 2	60.8	11 519.2
LSD_{05}	4 626.98	2.55	1 894.41

Source: Upytė Experimental Station, 2010-2011.
* significant differences at 95 % probability level.

in 2009 for the varieties ‘Beniko’, ‘Bialobrzeskie’, ‘Epsilon 68’, ‘Felina 32’ and ‘USO 31’ (Jankauskiene et al., 2010). In Denmark the total average dry matter yield of the cultivars ‘Fedora’, ‘Fedrina’, ‘Felina’ and ‘Futura’ was reported to be approximately 13 t ha^{-1} (Deleuran at al., 2006). Very high yields (up to 22.5 t dry matter ha^{-1}) were obtained in Italy when later cultivars were used (Struik et al., 2000).

In our resent trials, the best results of the absolutely dry mass yield were shown by the cultivars ‘Futura 75’ (11.8 t ha^{-1}), ‘Bialobrzeskie’ (11.6 t ha^{-1}) and ‘Epsilon 68’ (11.3 t ha^{-1}) in 2010. In 2011, the most productive were the cultivars ‘Beniko’ (13.1 t ha^{-1}) and ‘Futura 75’ (12.3 t ha^{-1}). The differences between the cultivars were insignificant, just in 2011 the cultivar ‘Fedora 17’ produced significantly lower dry mass yield (8.5 t ha^{-1}).

According to some authors (Werf et al, 2009 b), in hemp the relationship between yield and optimum plant density is approximated by the equation of its self-thinning line. In our investigation, we didn’t find any correlation between crop density (after full emergence or at harvesting) and the yield (of green or absolutely dry biomass) in 2010. But in 2011, some correlation between investigated parameters was found. Weak correlation was found between crop density after full emergence and green/dry biomass yield for cases of all varieties. Strong correlation (determination coefficient 0.99) was found for the variety ‘Bialobrzeskie’ between crop density at harvesting and green (4) and dry (5) biomass yield:

$$y = 60292.65 - 243.18x \quad (4)$$

where:

y – yield of green biomass, kg ha^{-1};

x – crop density at harvesting, plants m^{-2};

$$y = 22650.31422 - 85.98x \quad (5)$$

where:

y – yield of dry biomass, kg ha^{-1};

x – crop density at harvesting, plants m^{-2};

Similar correlations were found also for the varieties 'Fedora 17' and 'Felina 32'.

Conclusions

Nevertheless, the 8.8-33.7 % of fully emerged plants died, but the rest of the survived plants produced sufficiently high biomass yield. In 2010, hemp produced high amount (on average 32.3 t ha^{-1}) of green over-ground mass (stalks, leaves and panicles), and plants of 'Futura 75' produced significantly higher amount of green mass (38.7 t ha^{-1}) than the other cultivars tested. In 2011, the green biomass yield was a little bit lower (on average 29.4 t ha^{-1}) than that in 2010 (on average 32.3 t ha^{-1}). The highest amount of green biomass was produced again by plants of cultivar 'Futura 75' (33.2 t ha^{-1}), but the differences between the cultivars were not significant.

In 2010, plants of the tested hemp cultivars produced on average 10.5 t ha^{-1} of dry over-ground biomass, and 11.5 t ha^{-1} in 2011. The best results of the absolutely dry mass yield were shown by the cultivars 'Futura 75' (11.8 t ha^{-1}), 'Bialobrzeskie' (11.6 t ha^{-1}) and 'Epsilon 68' (11.3 t ha^{-1}) in 2010. In 2011, the most productive were the cultivars 'Beniko' (13.1 t ha^{-1}), 'Futura 75' (12.3 t ha^{-1}).

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EVALUATION OF REED RESOURCES IN KURZEME REGION IN LATVIA

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Abstract
The increasing demand for energy, limited resources of fossil fuel, as well as pollution of the environment and changes in the global climate have raised more interest about the renewable resources. Support to the use of renewable resources has become a very important part of European Union policy. The aim of this paper is to analyse the quantity of reed resources in Kurzeme region in Latvia, to produce clean energy. The use of reeds as a renewable energy resource allows economizing fossil fuels. The paper presents research results of reed resources in lakes of Kurzeme. The investigation of reed resources shows that in the region they are scattered and rational usage of them is connected with environmental aspects. There are 16 significant lakes for reed harvesting in Kurzeme region. The greatest amounts of reed resources are concentrated in the four lakes - Engures, Papes, Liepājas and Tosmares. Using distance control methods, it was stated that reed beds in Kurzeme exceeds an area of more than 7000 hectares. The potential yield of reed biomass is more than 50000 tons per year. Balanced harvesting of reed gives a positive influence on the environment.
Key words: renewable energy, environment quality, common reed, reed resources.

Introduction

Lakes of Latvia are characterized by eutrophication that often has a negative impact on lake biotopes. In Latvia there is no special interest in reeds. They grow on lake and river banks and in almost every pisciculture farm. Currently, insignificant amounts of reed are used in building. Reeds die off every year and decompose on the banks of lakes and pisciculture farms, creating emission of CH_4 in atmosphere. Nevertheless, as the costs of fossil energy resources are growing, the interest in possibilities of using the local biomass in power supply is also increasing. Previous studies show that reeds can be used as raw material in fuel production. (Čubars et al, 2009,Komulainen et al., 2008). In many countries the reed (*Phragmites australis)*, the most widespread reed in Latvia, is considered to be an invasive species. Reeds form big mono-specific growths that supersede other plants and endanger the biological diversity in biocenosis. There are special reed monitoring and control activities in many countries. To stop the reed invasion, such methods as mechanical removal, drainage, cultivation with discs, granulation, burning, abatement by herbicides, as well as biological control methods, are used.

In Latvia there is no monitoring or accounting system of reed growths. Eutrophication processes are taking place in natural lakes and in artificial water bodies of Latvia, but the intensity of these processes is not clarified. The reed-covered areas in Latvia are not explored yet. To evaluate the reeds as renewable resources and their amount in lakes of Kurzeme region that are potentially important for reed extraction, the reed-covered areas were analyzed and potential reserves of biomass in these lakes were calculated.

Materials and Methods

The object of study is the lakes, common reed *Phragmites australis*. Reed is a perennial, tall (usually 120-250 cm) grass calescent family plant.

The rootstock type is decumbent. The straw is bare, sharp, firm, slightly glazy, and thick (d= 0.7-1.2 cm). Leafs are lanceolate (20-40 cm length, 2-4 cm wide), aeruginous, nibbed, the lower side is mat, volva is long. The trigger of leaf is furry. Panicles are long (20-40 cm), dense and reddish brown.

Reeds are widespread in Latvia. Usually they are routed in large, mono dominant beds in water reservoir and sea shores, moist woods, marshes and wet meadows. With its decumbent rootstock (vegetative sprout can reach 10-15 m) they rapidly occupy new areas. This species (mostly mono dominant) belongs to plant sets in forested fens and overgrown shallow waters: Cl. Phragmitetea, All. Phragmition, and other unities of this class. (Phragmites Australis, 2011).

The research on reed distribution was made in natural and artificial water bodies of Kurzeme region that are potentially important for the extraction of reed biomass. Potentially important lakes were identified using literature analysis.(Database of Latvian lakes, 2011). The most important criteria for the evaluation of importance: the mirror surface of lake is more than 100 ha and the level of overgrowth is more than 3%. Lakes that do not correspond to these criteria were not considered to be important and were not used to calculate the total potentially usable reed resources. A reed amount in lakes with a smaller surface area and a lower overgrowth level are relatively insignificant and currently their use is Latvia is not topical. At first, we need to study the most important resources that are concentrated in relatively small territory and

Figure 1. **Reed growths in the Southern part of Liepājas Lake**

currently are not used appropriately. Reed extraction in small lakes with insignificant reed surfaces involves high transportation costs and may be economically unprofitable. The suitability of every lake for the extraction depends on extraction technology and specifications.

The detection of reed surfaces was made using the method of distant survey in computer program ARC GIS. The reed-covered areas in every lake were identified using ortophotos of 2010. (Figure 1)

The bushed reed growths were not taken into account, whereas the areas covered with clubrushes were used to calculate the total reed surfaces.

To calculate the potential reed biomass in Kurzeme region, the results of reed studies in the lakes of Latgale region were used. The method of direct measurement in nature helped to define the amount of reed resources extractable from 1m^2 of reed growth in lakes and pisciculture farms. Studies were made in 20 lakes and pisciculture farms of Latgale region. The part of

Table 1

Characteristics of reed resources in Kurzeme region

Lake	Total area of lake, ha (Database of Latvian lakes, 2011)	Middle deep of lake, m (Database of Latvian lakes, 2011)	Reed area, ha	Reed biomass potential, tons**	Average overgrow, %
Engures L.	4130.7	0.4	3194	22997	77.3
Liepājas L.	3715	2	1554	11189	41.8
Papes L.	1205	0.5	2087	15000	71.5*
Durbes L.	670	3.9	60	432	9
Puzes L.	520.5	12.1	42	302	8.1
Tosmares L.	405	0.5	314	2261	77.5
Būšnieku L.	330	1.2	38	274	11.5
Rimzātu p.	277	No data	12	86	4.3
Cieceres L.	276.8	7.2	18	130	6.5
Sasmakas L.	252	3.8	19	137	7.5
Vilgāles L.	242.5	1.9	36	259	14.8
Spāres L.	201.1	2.3	24	173	11.9
Liekna L.	200	No data	8	58	4
Laidzes L.	170.5	4.4	36	259	21.1
Lubezers	129.6	1.7	9	65	6.9
Gulbju L.	115.5	1.5	13	94	11.3
Total	**12841. 2**		**7464**	**53716**	

** - The level of overgrowth in Papes Lake was calculated adding the areas of wetlands located nearby and covered with reed, to the mirror surface of the lake.*

*** - The potential amount of reed biomass was calculated using the average indexes of biomass in the lakes of Latgale region. For every lake, the indexes may differ, it depends on characteristics of reeds in the concerned lake.*

reeds that in wintertime is placed above ice was used to make calculations. Measuring and weighting of samples was performed in 10 sampling plots of every lake. The area of sampling plot was 25m^2. The plots were chosen in places where density of overgrowth was average. The density of overgrowth was determined inspecting the reed area. The studies of lakes in Latgale region show that reeds are different. Their biomass is 0.51-0.93 kg m$^{2\ -1}$ from the reed growth (the relative humidity 15-20%). The average biomass of lakes is 0.72 ± 0.32 kg m$^{2\ -1}$ (Čubars, 2010).

Results and Discussion

Lakes cover 1.5% of the territory of Latvia, i.e. 1000 km^2. 2256 lakes are larger than 1 ha. 16 lakes are larger than 10 km^2 and account for 45% of the total surface of lakes in Latvia. The reed is one of the most widespread aquatic plants, it occupies larger or smaller areas in all water bodies of Latvia.

Studies show that in Kurzeme region there are 17 lakes with mirror surface larger than 100 ha. Their total mirror surface is 16310.4 ha.

In all the studied lakes the level of overgrowth is higher than 3% with the exception of Usmas Lake where the reed growth covers 2.1% of mirror surface of the lake and it was not taken into account during the calculations of total reed resources. Reed growths of Usmas Lake cover 72 ha and they are dispersed over all the aquatorium along the bank.

The total amount of important reed resources in Kurzeme region (in lakes that correspond with the criteria of study) grow on a territory of 7464 ha and its potential is 53 716 tons of biomass per year. (Table 1).

The most important reed resources are located in the littoral lakes with small average depth. The level of their overgrowth is high. The largest reed-covered areas (95.8%) are concentrated in four lakes of this region: Engures, Papes, Liepājas and Tosmares. These four lakes are considered to be the most important and the most suitable for reed extraction in Kurzeme region. Papes, Liepājas and Tosmares Lakes are located relatively close to each other, therefore the reeds extracted in these lakes could be processed in one place. (Figure 2).

The largest reed-covered areas were observed in Engures Lake – 3194 ha. The total potential amount of biomass is approximately 23 000 tons per year. The reeds in Engures Lake cover 77.3% of its total surface. The largest part of reed-covered areas consists of big monodominant growths in the Northern, Northwestern

Figure 2. **Location of reed growths in Kurzeme region**

and Southern parts. Some reeds grow in relatively small reed blocs with the surface of 0.3-10 ha, and they are dispersed over all the aquatorium.

The second largest reed-covered area of Kurzeme region is observed in Papes Lake. The biggest reed-covered areas are located in the Northern, Northwestern and Southern parts of the lake. The reed growths are found not only on the territory of lake, but also in the wetlands located nearby. The total reed-covered territory and the lake constitute 2919 ha, the total reed area – 2087 ha. The potential amount of biomass is approximately 15 000 tons per year, the level of overgrowth – 71.5%.

The biggest reed-covered areas of Liepājas Lake are located in its Southern and Northern part. Moreover, these areas are situated along the Eastern and Western banks constituting a relatively wide zone (50-500 m). The reed-covered area – 1554 ha, the potential amount of biomass – approximately 11189 tons per year. The level of overgrowth in Liepājas Lake is 41.8% and this index is the lowest of all the four richest lakes.

Tosmares Lake, which is situated close to Liepājas Lake, is relatively small. Its mirror surface is 405 ha, reeds grow on a surface of - 314 ha. The total annual potential is approximately 2261 tons of biomass per year.

Another 12 lakes of Kurzeme region (Durbes Lake, Puzes Lake, Būšnieku Lake, Rimzātu ponds, Cieceres Lake, Sasmakas Lake, Vilgāles Lake, Spāres Lake, Liekna Lake, Laidzes Lake, Lubezers, Gulbju Lake) that were considered to be important based on the criteria of studies, constitute only 4.2% of the total reed resources – 313.5 ha, i.e., 2257 tons of biomass. These lakes are characterized by relatively big average depth and low level of overgrowth. Principally, the reeds grow along the lake banks constituting zones of 10-50m.

Papes Lake, Liepājas Lake, Tosmares Lake, Engures Lake and Liekna Lake, as well as the Northern part of Durbes Lake are the territories of Natura 2000. This fact might impose restrictions on the reed extracting. (Natura-2000, 2011)

Conclusions

In Kurzeme region there are 17 lakes with the mirror surface larger than 100 ha. Their total mirror surfaces constitute 16310.4 ha.

In all the studied lakes the level of overgrowth is higher than 3%, with the exception of Usmas Lake where reed growths are observed in 2.1% of the total mirror surface of this lake.

The total important reed resources (in lakes that correspond with the criteria of studies) grow in 16 lakes of Kurzeme region, they cover 7464 ha and their potential is 53 716 tons of biomass per year.

The most important reed resources are located in littoral lakes with small average depth. The level of their overgrowth is high. The largest reed-covered areas (95.8%) are concentrated in 4 lakes of this region: Engures Lake, Papes Lake, Liepājas Lake and Tosmares Lake. These four lakes are the most important and the most suitable for reed extraction in Kurzeme region.

Papes, Liepājas and Tosmares Lakes are located relatively close to each other, therefore the reeds extracted in these lakes could be processed in one place.

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THE EVALUATION OF DRY MASS YIELD OF NEW ENERGY CROPS AND THEIR ENERGETIC PARAMETERS

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Abstract
The investigations of local as well as introduced tall perennial grasses for biofuel production is an important object in agronomical science. In order to determine the effect of lime and nitrogen fertilisation on new unconventional energy plants (virginia mallow (*Sida hermaphrodita* L. Rusby), cup plant (*Silphium perfoliatum* L.) and common mugwort (*Artemisia vulgaris* L.), the investigations were carried out in Vėžaičiai branch of the Lithuanian Research Centre for Agriculture and Forestry in 2009 - 2011. The field experiments comprised of 3 levels of liming (i.e. not limed, limed at 0.5 rate, limed at 1.0 rate) and 3 levels of nitrogen rate (i.e. 0, 60 and 120 kg ha^{-1}).
Both liming and nitrogen application were two factors which positively affected the increase of cup plant, common mugwort and virginia mallow above-ground dry mass yields, although not statistically reliable (at a 95% probability level) in some treatments. Liming had no significant influence on common mugwort productivity. Out of three species, cup plant accumulated a substantially higher dry mass amount. The calculated data of the energy balance parameters shows that the share of energy bounded in lime and nitrogen fertilizers comprised a most substantial part of the energy expenses. Cup plant accumulated the highest amount of total energy and achieved the highest net energy balance (energy output - energy input ratio). The increase of the liming and nitrogen rates frequently caused the decrease of net energy balance.
Key words: lime, nitrogen, cup plant, common mugwort, virginia mallow, energetic evaluation.

Introduction

The biomass resource can be considered as organic matter, in which the energy of sunlight is stored in the chemical bonds. Commonly, the „ideal“ energy plants species have the following attributes: 1) high productivity (maximum dry mass production); 2) low energy input to produce; 3) low cost; 4) composition with the least contaminants; 5) low nutrient requirements. These characteristics also depend on the soil and climatic conditions (McKendry, 2002). Some authors emphasize the superiority of perennial crops over annuals due to higher cultivation profitability.

In recent years, a fair amount of attention has been focused on the investigation of local and introduced species that are potentially relevant for energy purposes.

Some introduced species, belonging to *Miscanthus* as well as *Polygonum* genus, produce high above-ground biomass yield, and were grown as ornamental species. The expansion of *Miscanthus* genus to the north is restricted by its low resistance to negative temperatures (Clifton-Brown et. al., 2003). Virginia mallow (*Sida hermaphrodita* L. Rusby) and Cup plant (*Silphium perfoliatum* L.) are from North America. The sparse available data indicates that both plants accumulate high amounts of biomass and thus could be cultivated and utilized for various kinds of energy purposes, i.e. direct combustion, pellets or biogas production (Borkovska and Wardzinska, 2003; Kovalski, 2004; Heneman and Červinka, 2007; Kovalski, 2007).

Artemisia genus species is widely prevalent throughout the Northern Hemisphere and characterized as high as 18.83 KJ kg^{-1} energy value (Van Epps and Barker, 1982; Barney and DiTommaso, 2002). In Lithuania, the investigation of *Artemisia* genus, and other tall grassy species for bioenergy purposes are still in the initial stages (Kryževičienė et al., 2010).

Naturally acidic *Albeluvisols* and *Fluvisols* contain high amounts of toxic for plants' mobile aluminium (Plesevičius, 1995), and the soil acidification process is in progress due to a high annual amount of precipitation (Mažvila et al., 2004). In this respect, Western Lithuania region is less favorable for profitable farming. It is supposed that energy plants could occupy the area of approx. 10-15% of all abandoned areas (Jasinskas et al., 2003). Thus, in the near future, a part of agricultural land could be used for energy crop cultivation. Special attention should be given to the species that can tolerate low soil pH.

Research aim – the productivity evaluation of unconventional agricultural plant species as well as the energetic assessment of growing technology.

Materials and Methods

The trials were set up in Vėžaičiai branch of the Lithuanian Research Centre for Agriculture And Forestry, Western Lithuania (55º43´N, 21º27´E) during 2009 – 2011. Prior to establishing the experiments, the site was occupied by black shallow. The soil of the experimental site is Dystric Albeluvisol (FAO, 1998), moraine loam. The upper soil layer (0-20 cm) contained pH KCl – 4.2-4.8, mobile P_2O_5 – 35-120 mg kg^{-1}, mobile K_2O – 140-209 mg kg^{-1}, hidrolytic acidity – 21.9-62.1 mekv kg^{-1}, mobile Al – 10.7-50.9 mg kg^{-1}.

An experimental scheme was composed of two factors: lime rates (not limed, 0.5 liming rate (3.0 t ha^{-1} $CaCO_3$), and 1.0 liming rate (6.0 t ha^{-1} $CaCO_3$)) – thus, forming three different pH strips, and nitrogen rates (0, 60, and 120 kg ha^{-1}). The liming was done just before the establishing on the experiments, particularly on the 20th of April.

Mugwort and cup plant were planted in 2008, and virginia mallow – in 2009. Cup plant and virginia mallow were planted in 10 metre length rows with 1 m spacing between them and 0.5 m between plants in rows. Thus, 1 ha was comprised of 20,000 plants. Each mugwort treatment comprised three 10 metre length rows. The distance between the rows – 0.75 m, and 0.5 m between each plant.

Ammonium nitrate was used as a source of nitrogen. A 60 kg ha^{-1} nitrogen rate was broadcasted prior to the beginning of vegetation. The rest of the 60 kg ha^{-1} nitrogen fertilisation was done at the beginning of July (3rd treatment). Phosphorus (single superphosphate) and potassium (potassium chloride) were applied just prior to the beginning of vegetation. The rates of phosphorus and potassium fertilisation were equal for all the treatments - 60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O.

The harvesting of cup plant and mugwort was done at the last stages of vegetation, particularly in 2009 on 16th of September, in 2010 on 30th of September, and in 2011 on 22nd of September. To determine the dry mass productivity, plant samples were dried to air-dried moisture content, and were later on recalculated to t ha^{-1}.

The biomass energy value (MJ kg^{-1}) for all investigated plants (except the treatments applied at the 60 kg ha^{-1} nitrogen rate) was evaluated according to the chemical tests executed at the Agricultural Institute's of the Lithuanian Research Centre for Agriculture and Forestry Chemical Research Laboratory in 2010.

The significance of liming and nitrogen fertilization was analyzed using analysis of variance (ANOVA), by choosing LSD_{05} to assess the significance (Tarakanovas, Raudonius, 2003).

By calculating the total energy expenses (GJ ha^{-1}), we included the direct energy expenses (ploughing, cultivation, protection from weeds, biomass harvesting, and transportation), indirect energy expenses (share of energy in fertilisers and herbicides), machinery energy consumption, and human labour input.

Energy output (GJ ha^{-1}) was calculated by multiplying dry mass yield (t ha^{-1}) by energy value of the plants (MJ ha^{-1}). Net energy ratio (or energy balance) (NER) was calculated by the equation (acc. to Shahin et al., 2008).:

NER = energy output (GJ ha^{-1}) - energy input (GJ ha^{-1}) (1)

Weather conditions. In 2009, the weather was cooler, meanwhile the temperature from the end of June until the middle of September was slightly higher. The amount of precipitation during vegetation was 437 mm and comparable to annual average; the sum of active temperatures - 2064 ºC. The 2010 growing season was uneven with periodical heavy rainfalls with two hot and dry weather periods in between them. During the April – September period, the amount of precipitation was 620 mm, the sum of active temperatures - 2246 ºC. Overall in 2011, the weather was warmer in compare with previous vegetations; the higher amount of precipitation felled in the second half of vegetation and amounted to 540 mm; the sum of active temperatures – 2400 ºC.

Results and Discussion

The data of cup plant dry mass productivity is presented in Fig.1. In all the experimental years, the effect of liming and nitrogen application was similar. With reference to average data, the application of the highest lime rate had a positive effect on dry mass increment by 15.5% (in 2009), 44.2% (in 2010) and 22.9% (in 2011). In turn, the application of 120 kg ha^{-1} nitrogen rate caused the increase of dry mass yield by 41.1% (in 2009), 20.1% (in 2010) and 20.0% (in 2011). Thus, the application of highest lime and nitrogen rates caused the highest dry mass productivity. In both the subsequent years, the cup plant productivity increased sharply and outweighed the first year's dry mass

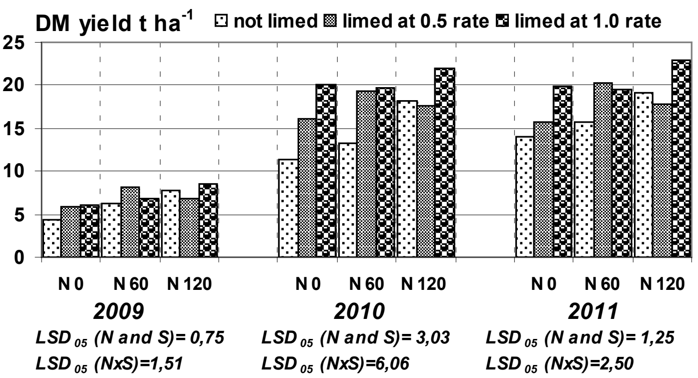

Figure 1. **The productivity of cup plant (t ha^{-1}) as influenced by liming and nitrogen fertilisation (kg ha^{-1})**

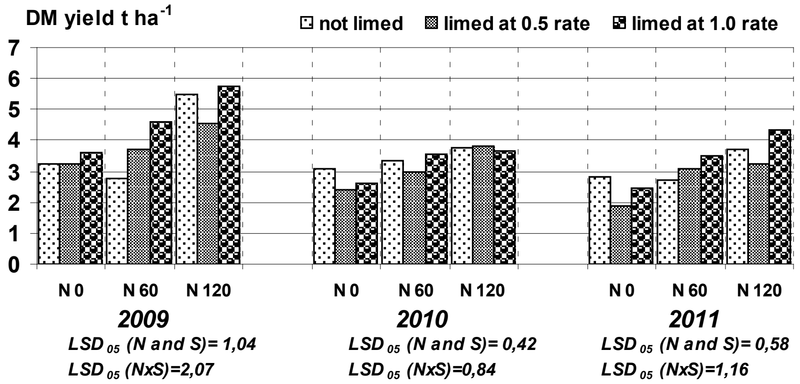

Figure 2. **The productivity of common mugwort (t ha^{-1}) as influenced by liming and nitrogen fertilisation (kg ha^{-1})**

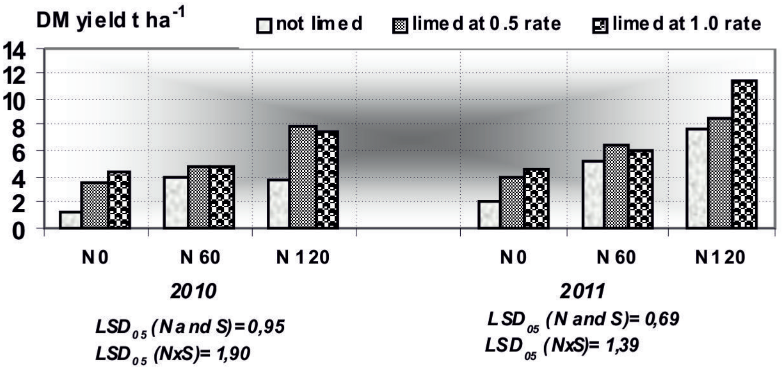

Figure 3. **The productivity of virginia mallow (t ha^{-1}) as influenced by liming and nitrogen fertilisation (kg ha^{-1})**

productivity by 259% (in 2010) and 267% (in 2011). These results correspond with other reports that the first year's yield is poor, but it increases in subsequent years (Filatov et al., 1986).

It is noted that the application of lime only (without nitrogen) showed that the cup plant productivity was fairly high and was equal to the impact of nitrogen fertilisation in many treatments. In this respect, cup plant has a well developed root system and ability to utilize a substantial part of nitrogen from deeper soil layers. It seems that drought periods during vegetation had no substantial effect for productivity. Cup plant has a well developed root system. Some roots grow down (roots penetrate to 30-150 cm), others spread radially under the soil surface (Stanford, 1990).

Thus, the cup plant dry mass productivity was far superior to other investigated species.

In 2009, the application of highest – 120 kg ha^{-1} nitrogen rate had the highest importance for common mugwort dry mass productivity in all pH strips (Fig. 2). The liming influence was less noticeable and less significant than the 95% probability level. The common mugwort above-ground dry mass productivity was substantially reduced in both the subsequent years and was lower by 19.7% (in 2010) and 24.8% (in 2011) in comparison with the 2009 vegetation results. As in the first year of vegetation, liming had no significant influence to the dry mass increment. The optimal rate of nitrogen fertilisation was 60 kg ha^{-1} (in 2010) and 120 kg ha^{-1} (in 2011). The decrease of dry mass increment and herewith the inferior affect of nitrogen fertilisation could happen as a result of rainless periods during the stage of intense growing.

According to the reports of other authors, meteorological conditions (moisture and temperature) can cause substantial variation of common mugwort dry mass yield – from 5.55 to 8.00 t ha^{-1} (Kryževičienė et al., 2010).

Fig.3 represents the data of virginia mallow productivity of both successive years. In the first year of growth (i.e. 2010), the significant influence of liming was observed by application of the average 3.0 t ha^{-1} rate. The application of highest liming rate had no significant effect on dry mass yield. In many treatments, the application of nitrogen fertilisers was favorable for dry mass productivity. In addition, positive and reliable interaction was observed between liming and the 120 kg ha of nitrogen rates.

In 2011, virginia mallow dry mass yield was 33.5% higher than in previous vegetation. In all the cases,

Table 1.

Energetic evaluation of common mugwort, cup plant and virginia mallow in 2010

Treatments	Total energy expenses for cultivation GJ ha^{-1}	Total accumulated energy in biomass, GJ ha^{-1}			Net energy ratio (NER)		
		Common mugwort	Cup plant	Virginia mallow	Common mugwort	Cup plant	Virginia mallow
N0 (not limed)	7.5	51.6	186	22.7	44.1	178.5	15.2
N120 (not limed)	11.0	65.6	289	67.7	54.6	278	56.7
N0 + 0.5 liming rate)	13.0	47.6	248	61.6	34.6	235	48.6
N120 + 0.5 liming rate	16.4	68.4	295	140	52.0	278.6	123.6
N0 + 1.0 liming rate	18.4	49.0	335	75.7	30.6	316.6	57.3
N120 + 1.0 liming rate	21.9	63.5	374	131	41.6	352.1	109.1

virginia mallow dry mass yield responded positively to liming as well as the application of 120 kg ha^{-1} nitrogen rate. Thus, the combination of highest liming and nitrogen rates as well as their interaction was the cause of highest dry mass productivity during the experiment – 11.5 t ha^{-1}.

In comparison with other investigated species, the use of liming and nitrogen fertilisation had the greatest effect on virginia mallow dry mass productivity. In 2010, by the application of the highest 1.0 liming rate, the average dry mass yield increased by 84.0% and the 120 kg ha^{-1} nitrogen rate – by 108.5%; meanwhile according to the 2011 vegetation results, liming and nitrogen fertilisation caused the increase of dry mass yield by 36.5% and 263.1%, respectively.

The report of other authors shows that virginia mallow productivity was low at first two growing years, but increased by approximately 3 times in subsequent years (Borkowska et. al., 2001). It is observed that virginia mallow productivity is sensitive to unfavourable soil physical-chemical properties (Borkowska et. al., 2009).

Energetic evaluation. The data of the energy parameters (in 2010) are presented in Table 1. Since the technological operations are the same for all three plants, the energy expenses for cultivation as presented in the Table 1. are equal.

Depending on the treatment, the total energy expenses for cultivation varied 7.5 to 21.9 GJ ha^{-1}. These wide differences were determined by the different fertilisation, particularly of the liming and nitrogen application. The share of energy in lime and mineral fertilisers (especially ammonium nitrate) comprised 32.8 to 76.1% of all the consumed energy expenses. Out of all the energy expenses, the energy for different agricultural operations comprised a mere 0.26–0.28 GJ ha^{-1}

Liming and nitrogen application highly affected the amount of total accumulated energy (GJ ha^{-1}) in cup plant and virginia mallow biomass and had a less influence on energy accumulation in common mugwort biomass. Out of three species, the highest amount of total accumulated energy was observed in cup plant biomass (from 186 to 374 GJ ha^{-1}).

The net energy ratio (energy output - input or NER) varied on a high scale: from 30.6 to 54.6 (for mugwort) and from 17.04 to 26.36 (for cup plant). It is noticed that the decrease of common mugwort and cup plant NER was highly influenced by the high 1.0 liming rate (or 6.0 t ha^{-1} $CaCO_3$). The share of the accumulated energy was higher than the additional share of energy obtained by the effect of liming (especially inherent for mugwort). The influence of nitrogen fertilisation (120 kg ha^{-1}) was less evident. Contrarily, the virginia mallow NER was substantially increased by the application of 120 kg ha^{-1} nitrogen and liming by 0.5 rate (or 3.0 t ha^{-1} $CaCO_3$). The NER slightly decreased by the application of 1.0 liming rate.

Commonly, the positive NER balance is receivable due to photosynthetic active radiation, which inspires the accumulation of solar energy in plants. Other means, such as fertilisers, pesticides, soil cultivation, etc. only enable plants to accumulate a higher amount of energy in plants (Aleksynas, 1990).

Conclusions

Liming and nitrogen application caused a significant increase of cup plant and virginia mallow above-ground dry mass productivity in all the years of the experiment. The mugwort productivity was affected only by nitrogen application; liming did not have a substantial effect. In comparison with mugwort and virginia mallow, cup plant productivity and the amount of total accumulated energy in biomass was substantially higher.

The indirect energy consumption (especially the share of energy bounded in lime and nitrogen fertilisers) comprised a substantial part of the energy input. High rates of liming and nitrogen application highly affected energy accumulation in cup plant and virginia mallow above-ground biomass and had a lesser effect on common mugwort. The net energy ratio (NER) for common mugwort and cup plant frequently decreased as the result of liming and nitrogen fertilization (except for virginia mallow).

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INOCULATION AS AN ELEMENT OF ENERGY SAVING IN THE CULTIVATION TECHNOLOGY OF GRAIN LEGUMES UNDER CONDITIONS OF THE FOREST-STEPPE OF UKRAINE

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Abstract
Highly effective, competitive and complementary strains *Rhizobium leguminozarum bv. viceae* B-9 for faba bean cultivar Bilun and *Bradyrhizobium japonicum* 71-T for soybean cultivar Femida that are recommended as a basis for production of bio-preparation for seed inoculation while growing annual grain legumes in agrocenosis of the Forest-Steppe are revealed.
Key words: soybean, faba beans, innoculation, Bradyrhizobium japonicum, Rhizobium leguminozarum bv. viceae, crop productivity.

Introduction

Improvement of nitrogen nutrition of plants is the main factor of the crop yield increase. Application of “industrial” nitrogen of mineral fertilizers provides balancing of soil deficiency in nitrogen. But industrial fertilizer production demands substantial energy costs. For example, in the USA nearly 2.5% of annual reserves of natural gas are spent on the synthesis of nitrogen fertilizers. Therefore, under conditions of global energy crisis there is a growing interest in biological systems that fix atmosphere nitrogen using sun energy accumulated in the process of photosynthesis (Posypanov, 1993). The study of this process is an urgent problem of biology and agricultural science. On the one hand, it is necessary to search potentiality of biological nitrogen fixation, and on the other hand, to make highly active competitive strains of bulb bacteria and other nitrogen fixers.

Grain-legume crops play an important role in mobilization of biological nitrogen that is essential for the general nitrogen balance in farming as well as for the increase of crop yield and protein content in it. It is known that the positive role of grain-legume crops in agriculture is connected with the activity of bulb bacteria with which these crops are in close symbiotic relations. Productivity of grain-legumes, increase of their adaptive potential, accumulation of biological nitrogen and protein depend substantially on the interrelations of macro- and microsymbionts in each case.

It should be mentioned that many cultivars of grain-legumes are not very susceptible to inoculation by active strains of bulb bacteria, as a result of which their root system is populated with “local” low active strains. That is why symbiosis must be considered from the point of view of a culture – nitrogen fixing bacteria and a variety – strain of nitrogen fixing bacteria. Results of researches carried out by I.A.Tykhonovych have shown that in soybean rhyzosphere, in spite of the presence of vigorous competitive strains of bulb bacteria, competitively weak strain was dominating as its genotype corresponded to the genotype of the host plants. In this case variety specificity of macrosymbiont has been shown (Tikhonovich, 1989). Application of highly effective strains of bulb bacteria in symbiosis with modern cultivars of grain-legumes has increased their productivity by 10-30% and protein content in seeds by 2-6%, even under condition of availability in the soil of aborigine bacteria or those that have been introduced earlier (Didovich et al., 2010). Thus, seed inoculation by bacteria fertilizers is a simple, cheap and compulsory agrotechnical measure that provides the increase of nitrogen fixing ability of grain legume crops, their yield capacity and improvement of the yield quality of both inoculated sowings and subsequent crops in rotation (Berestetskyi , 1978; Bazilinskaya, 1989).

Materials and Methods

Researches were carried out in 2006-2010 on the grey forest mid loamy soils, an arable layer of which (0-30 cm) contained 1.94% of humus.

Faba bean cultivar Bilun and soybean cultivar Femida selected by the Institute of Feed Research and Agriculture of Podillya of the Ukrainian Academy of Agricultural Sciences and grown according to the modern zone technology without application of mineral nitrogen fertilizers, insecticides and herbicides were sown; weeds were destructed using agrotechnical methods. The yield was harvested by combining with subsequent re-calculation of seed mass for 100% purity and 14% moisture content. The trials were repeated four times, variants were located systematically. The area of the registered plot was 25 m^2.

Rhizobia strains from the collection of the Russian Institute of Agricultural Microbiology of the RAAS and the Southern Research Station of the Institute of Agricultural Microbiology and Agro-industrial Production of NAAS were used in trials. Efficacy of symbiotic nitrogen fixation of stains *R.leguminozarum bv. viceae* with faba bean plants was estimated in comparison with production strains 248b, 0418, 0419, strains *Bradyrhizobium japonicum* with soybean plants – with strain-standard 634b and production strains M-8, 36 and variant without seed treatment of these crops according to methodical recommendations (Volcogon et al., 2010). In 1-2 hours before sowing the seed was watered (2% of mass) in control, in variants with strains – with water suspension of 7 day culture of rhizobia in such a proportion – 10^6 bacteria/seed. Statistic treatment of obtained results was carried out using the method of disperse analysis (Dospekhov,1985).

Results and Discussion

It is revealed that in all variants with inoculation bulb bacteria on the roots at the flowering phase of faba beans and soybean were rosy and big in comparison with control where formation of small root bacteria which had formed during infection by rhizobia of the soil population was observed.

In all variants with seed inoculation of faba beans and soybean, there was increase of their yields by 9.0-24.3 % and 4.2-13.6 % respectively in comparison with the control

Table 1

Faba bean seed yield depending on the influence of strains *Rhizobium leguminozarum bv. viceae*, t/ha (average for 2006-2009)

Trial variant	Crop yield, t/ha	Increase before control	
		t/ha	%
Without inoculation (control)	2.39	-	-
Production strains:			
248 b	2.72	0.33	13.7
0418	2.81	0.42	17.5
0419	2.91	0.52	21.8
Prospective strains:			
261	2.61	0.22	9.0
B-8	2.84	0.45	18.8
B-9	2.97	0.58	24.3
B-15	2.76	0.37	15.3
B-16	2.85	0.46	19.2
B-17	2.69	0.30	12.4
B-18	2.76	0.37	15.3
$LSD_{0,95}$, t/ha	0.103	-	-

Table 2

Soybean seed yield depending on the influence of strains *Bradyrhizobium japonicum*, t/ha (average for 2006-2010)

Trial variant	Crop yield, t/ha	Increase before control	
		t/ha	%
Without inoculation (control)	2.14	-	-
Strain-standard:			
634b	2.41	0.27	12.6
Production strains:			
M-8	2.26	0.12	5.6
36	2.23	0.09	4.2
Perspective strains:			
71-T	2.43	0.29	13.6
X – 2	2.38	0.24	11.2
640 b	2.36	0.22	10.3
19	2.31	0.17	7.9
33	2.31	0.17	7.9
$LSD_{0,95}$, t/ha	0.035	-	-

variant against a background of the soil population (Tables 1, 2).

Among production strains for faba beans, the best result was shown by bulb bacteria strain 0419. Seed yield of the crop was 2.91 t/ha that was 0.52 t/ha or 21.8 % more than in control and 0.1-0.19 or 3.6-7.0 % more in comparison with other production strains.

Seed inoculation by prospective strain B-9 provided maximum seed yield of cultivar Bilun 2.97 t/ha that was 24.3 % more than in control and 2.5 % more in comparison with strain 0419 that is the best one among production strains.

Seed inoculation of soybean cultivar Femida by various strains of bulb bacteria have shown that strain-standard 634b appeared to be the best one among production strains. Crop yield in this variant was 2.41 t/ha that was 0.27 t/ha or 12.6 % more than in control against a background of the soil population of rhizobia.

It should be mentioned that production strains of bulb bacteria M-8 and 36 provided a crop productivity of 2.26 and 2.23 t/ha that was 6.2 and 7.5 % less in comparison with strain-standard 634b and 2.0-7.0% less than in prospective strains of bulb bacteria.

Strain *Bradyrhizobium japonicum* 71–T appeared to be the most efficient selection strain for seed inoculation. It provides a 13.6 % seed yield increase in comparison with control, a 1 % increase in comparison with strain-standard 634 b and a 7.5 and 9.0 % increase – with production strains M-8 and 36.

It is determined that seed inoculation of faba bean and soybean both increases the level of crop productivity and improves seed quality, particularly it increases crude protein content.

Table 3

Influence of seed by strains *Rhizobium leguminozarum bv. viceae* on the crude protein content in faba bean seed, % (average for 2006-2009)

Trail variant	Crude protein content, %
Without inoculation (control)	26.84
Production strains:	
248 b	28.32
0418	27.17
0419	28.36
Perspective strains:	
261	27.83
B-6	27.24
B-8	28.61
B-9	28.84
B-15	27.87
B-16	27.85
B-17	27.67
B-18	29.03

Table 4

Influence of seed inoculation by strains *Bradyrhizobium japonicum* on the crude protein content in soybean seed, % (average for 2006-2009)

Trial variant	Crude protein content, %
Without inoculation (control)	34.19
Strain-standard:	
634 b	38.12
Production strains:	
M-8	37.29
36	37.91
Perspective strains:	
71-T	39.53
X – 2	38.92
640 б	35.62
19	38.16
33	38.33

Thus, seed treatment with both production and prospective strains of bulb bacteria increased crude protein content in faba bean seed by 0.33-2.19 % and in soybean seed by 1.43-5.34% in comparison with the control variant against a background of soil population of rhizobia populations (Tables 3, 4).

Thus, strains 0419 and 634 b appeared to be the most efficient strains among production ones for faba beans and soybean. They provided 28.36 % and 38.12 % crude protein contents in seed.

Strain B-18 appeared to be an effective one among perspective strains of bulb bacteria for faba beans. Crude protein content in this variant was 29.03 % that was 2.19 % more than in control and 0.67 % more in comparison with the best strain among production strains 0419.

The strain of bulb bacteria B-9 provided lower crude protein content 28.84 %.

Under condition of seed inoculation of faba beans by other strains of bulb bacteria, crude protein content in seed fluctuated from 27.17 to 28.61 %.

The highest crude protein content in soybean seed (39.53 %) provided a prospective strain of bulb bacteria 71-T that was 5.34 % more than in control and 1.41% in comparison with strain-standard 634b.

Under condition of soybean seed inoculation by other production and prospective strains of bulb bacteria, crude protein content fluctuated from 35.62 to 38.92 %.

Conclusions

It is experimentally proved that seed inoculation by selection strains *Rhizobium leguminozarum bv. viceae* and Bradyrhizobium japonicum improves plant growth and development and facilitates formation of high level of high quality faba bean and soybean seed yield when grown on grey forest mid loamy soils in the Forest-Steppe zone of Ukraine, even against a background of soil population of bulb bacteria.

Comparative evaluation of the results of various strains *Rhizobium leguminozarum bv. viceae* and *Bradyrhizobium japonicum* for seed inoculation of faba bean and soybean have shown availability of variety specificity of the strain activity that has been revealed through supply of the determined productivity of these crops.

Highly effective, competitive and complementary strains *Rhizobium leguminozarum bv. viceae* B-9 for faba bean cultivar Bilun and *Bradyrhizobium japonicum* 71-T for soybean cultivar Femida that are recommended as a basis for production of bio-preparation for seed inoculation while growing annual grain legumes in agrocenosis of the Forest-Steppe are revealed.

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CEREAL GRAIN AS ALTERNATIVE FUEL IN LATVIA

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Abstract
Thermal energy is one of the most important energy types in Latvia. Thermal energy is acquired from coal, gas, wood as well as plant biomass – straw, grass, grain. Low quality grain which is not suitable for the use in either food or feed production could be used for heating. Technologically, the grain is suitable for the heating systems with automatic fuel feed. During the field trial that took place in State Stende Cereals Breeding Institute in years 2009/2010 and 2010/2011, the possibility of using grain of winter wheat (*Triticum aestivum* L.), rye (*Secale cereale* L.) and triticale (*Triticosecale* Wittm) in heating was examined. The content of C, O, and H of the grain was determined as well as the content of fibre, ash, phosphorus, potassium, and calcium. The grain yield was determined at the humidity of 14%. The higher heating value of grain (kJ kg^{-1}) was also determined, whereas while the lower heating value was calculated. Out of all the examined species of winter cereals the winter wheat was the most suitable for heating, taking into account its grain yield, heating values and ash content. Having examined the chemical composition of the dry matter of winter cereal grain, it was determined that it has a higher amount of phosphorus and potassium than the wood as mentioned in relevant scientific sources. These chemical elements negatively affect the ash melting temperature due to which the slag is formed in the heating boilers.
Key words: grain yield, higher and lower heating values, chemical composition, ash.

Introduction

It is important for Latvia to ensure an independent energy system. One of the most significant energy types in our latitude is thermal energy. Thermal energy can be acquired from coal, gas, wood as well as plant biomass — straw, grass, grain. It takes a long time for the fossil fuel resources (coal, gas) to replenish, while this process happens much faster for the plant biomass that renews every year by accumulating solar energy. The main characteristics of high-quality biomass are high biomass yield, low ash content, low humidity level and good combustibility. Due to the unpredictable weather conditions in Latvia there are certain years when the harvested grains cannot be used for either food or feed production (for example, because the grains have sprouted before harvesting, they are polluted with mycotoxines excreted by *Fusarium* etc. or because of other similar reasons). Grain that cannot be used for either food or feed is one type of biomass that could be used for heating. The choice of energy plants in a certain agricultural territory is determined by species and the technical facilities for cultivation. The energy plants have to be suitable for the climate of the territory, they have to fit into the rotation of crops in the farm and their yield level has to be appropriate. The most suitable energy plants are those that use the solar energy most efficiently, that need the least amount of chemical fertilisers and that have low humidity content at the time of the harvest (Venturi, Venturi, 2003). Technologically, the cultivation of cereals has been developed to a very good level, and grains are suitable for heating systems with automatic fuel feed.

The objective of the trial was to evaluate the possibility of using the grain of winter wheat (*Triticum aestivum* L.), rye (*Secale cereale* L) and triticale (*Triticosecale* Wittm) for heating.

Materials and Methods

Field trial

The field trial was carried out in the State Stende Cereals Breeding Institute in the autumn of 2009 and 2010. The conditions of soil were averagely suitable for growing winter cereals due to slightly diminished reaction of soil (Table 1).

Both years the white mustard was grown as a previous crop in the trial site. It was used as a green manure, and it was chopped and worked into the soil when the soil was ploughed in the autumn. The sowing rate was 450 germinating seeds per 1 m^2 for winter wheat, 400 germinating seeds per 1 m^2 for population rye ('Matador', 'Dankowskie Nowe') and triticale, and 200 germinating seeds per 1 m^2 for hybrid rye ('Placido'). The sowing was carried out on 18 September 2009 and on 14 September 2010. Complex fertiliser was used as a basic fertiliser, ensuring the total amount of 12-15 kg N ha^{-1}, 45-60 kg P_2O_5 ha^{-1} and 60-90 kg K_2O ha^{-1} in the autumn depending on the year.

For top-dressing, ammonium nitrate (N 34%) was used in the spring of each year:

- upon the renewal of vegetation process:
  - for winter wheat – 90 kg N ha^{-1};
  - for triticale and rye – 60 kg N ha^{-1};
- during the GS 31-32 of plant development for all examined species of winter cereals – 60 kg N ha^{-1}.

Table 1

Soil characteristics at the site of field trial

Year of trial	Soil	Granulometric composition of soil	pH KCL	Content of organic substance, g kg^{-1}	P_2O_5, mg kg^{-1}	K_2O, mg kg^{-1}
2009/2010	Podzolic soils Pv	sM	5.8	24	229	181
2010/2011	Podzolic-gley soils PG	sM	5.8	23	187	134

Source: made by authors

Both years the winter cereals were harvested with the experimental harvester WINTERSTEIGER DELTA (on 8 August 2010 and 4 August 2011). The harvester is equipped with weights and grain humidity meter for evaluation of the harvest. After the samples were dried on the platform driers, the grains were cleaned using the facility MINI PETKUS MP100. The harvest of winter cereals was recalculated in t ha^{-1} at the 14 % humidity and 100% purity.

Methods of chemical analysis

The following indicators – fibre (according to ISO 5498), crude ash (according to LVS 276:2000), P content (according to ISO 6492), K content (according to LVS EN ISO 6969), and Ca content (according to LVS EN ISO 6869) – were determined with appropriate standard methods at Laboratory of grain technology and agrochemical research of State Stende Cereals Breeding Institute. The content of C, O, and H was determined by using *Macro Elemental Analyzer-vario* MACRO CHNS (according to LVS CEN/TS 1504:2005). The higher heating value of grain (kJ kg^{-1}) (according to ISO 1928) was determined by using the oxygen bomb calorimeter "Parr 1341", but the lower heating value - by making calculations with the formula (1) in the Laboratory for test of Wood Chemistry Products at Latvian State Institute of Wood Chemistry:

$$Q_z = Q_a - 25(9H+W) \quad (1)$$

where

Q_z – the higher heating value of the fuel weight, kJ kg^{-1};

Q_a – the lower heating value of the fuel weight, kJ kg^{-1};

25 – the amount of heat needed for the evaporation of water, kJ kg^{-1};

H – the amount of hydrogen in the solid fuel, % ;

W – the amount of humidity in the solid fuel, % (Nagla et al., 1982).

Knowing the amount of grain yield and the amount of energy in MWh which can be obtained from 1 t of grains, the energetic value of the higher heating value in MWh as obtained from 1 ha was calculated. The mathematical processing of data was carried out by using the analysis of variance.

Results and Discussion

Grain that are not used for food or feed production can be used as a high-quality fuel. The biomass is considered to be of high-quality for heating purposes, if it corresponds to the following criteria: high yield; low ash content; low humidity content; higher heating values; high volume weight (Fuel supply handbook .., 2010).

The average grain yield for all the species of winter cereals, taking into account both years of cultivation, was 8.08 to 8.89 t ha^{-1} at 14% humidity. There was a difference in productivity of various species and varieties of winter cereals (Table 2), and a substantial ($p<0.05$) influence of meteorological conditions for crop formation was noted each year. The level of grain yield (8.83 – 8.99 t ha^{-1}) (Table 2) for the examined winter wheat varieties was very similar ($p>0.05$). For triticale the highest average yield ($p<0.05$) during two years of trial was provided by variety 'Dinaro' – 8.93 t ha^{-1}, while the highest yield during the entire trial period was provided by winter rye variety 'Placido' with the average yield of 9.24 t ha^{-1} (Table 2). The yield of all winter cereal species was substantially affected by the weather conditions during the trial years.

One of the most important indicators of fuel quality is heating value. The higher heating value is the amount of heat one fuel unit provides when it is fully burnt (Fuel supply handbook .., 2010). The net calorific value depends on the humidity content of the fuel (in this case – grain). Winter wheat and rye reached the highest level of the higher heating value – on the average 16084 and 16104 kJ kg^{-1} respectively (Table 2). According to the data acquired during two years of the trial it was slightly lower for triticale - 15975 kJ kg^{-1}(Table 2). Similar data are mentioned in the literature (Wachendorf, 2008). No substantial differences in higher heating values were observed among the examined species. According to the data

Table 2

Average grain yield, higher and lower heating value of winter cereals

Species, variety	Grain yield, t ha^{-1}	Higher heating value, kJ kg^{-1}	Lower heating value, kJ kg^{-1}
Winter wheat			
Skalmeje	8.83	16185	14258
99-115	8.84	16003	14085
Mulan	8.99	16065	14145
Average	8.89	16084	14162
RS/LSD $_{0.05}$	0.66	938	893
Triticale			
Valentino	8.24	15890	14008
Dinaro	**8.93**	15921	14006
0002-26	8.20	16114	14206
Average	8.46	15975	14073
RS/LSD $_{0.05}$	0.66	572	636
Winter rye			
Placido	**9.24**	16089	14195
Matador	7.53	16128	14194
Danskovij Nova	7.46	16095	14168
Average	8.08	16104	14186
RS/LSD $_{0.05}$	0.33	990	1124

Source: made by authors

of European Biomass Industry Association (European Biomass..., s.a.), the higher heating value of coal ranges from 20 to 30 GJ t^{-1}, of wood – from 18 to 19 GJ t^{-1}, while that of waste matter of agricultural products – from 15 to 17 GJ t^{-1}. According to the data acquired by Austrian researchers, the average higher heating value for grain of all cereals was 18610 kJ kg^{-1} (Friedel et al., 2005). According to the data of our research, the higher heating value of grain is lower than the one acquired by other researchers.

The chemical composition of biomass affects the quality of the fuel. The protein of biomass contains nitrogen. In the combustion process it completely transforms into a gas. The researchers have found that there is a correlation between the amount of nitrogen and the formation of nitric oxides - NO_x (Wachendorf, 2008, Shcolz, Ellerbrock, 2002). In our research, the amount of nitrogen in the grain of the examined winter cereals was in the range from 20.4 to 22.6 g kg^{-1} (Table 3) (2.04 – 2.26%). A substantially higher ($p<0.05$) amount of nitrogen in the winter wheat can be explained by a higher amount of used nitrogen fertiliser as it is also described in the research of other authors (Shcolz, Ellerbrock, 2002). According to the standards of Austria, the wood briquettes and granules should contain less than 0.3% of nitrogen. The amount of nitrogen in straw granules and bark briquettes has to be less than 0.6% (Obernberger, Thek, 2004). The research data shows that the grain of winter cereals contains a significantly higher amount of nitrogen.

The potassium in the biomass fuel causes corrosion of the heating boilers and lowers the ash melting temperature, resulting in slag formation (Shcolz, Ellerbrock, 2002). During the research it was found that the amount of potassium in the grains of winter cereals ranges from 3.92 g kg^{-1} (0.39%) to 5.08 g kg^{-1} (0.51%) (Table 3). The potassium amount in the forestry waste matter and dry matter of fast growing willow is lower – from 0.015 to 0.03% (1.5-3.0 mg kg^{-1}) (Beidermann, Obernberger, 2005). Phosphorus has not been found to negatively affect the emissions during the combustion process; however, elevated amount of phosphorus lowers the ash melting temperature (Shcolz, Ellerbrock, 2002). Our research the phosphorus content in the grain of winter cereals ranged from 2.52 to 2.98 g kg^{-1} (0.25 – 0.29%) (Table 3). There are data in the literature that amount of phosphorus is lower in wood than in grains of winter cereals, namely 0.03 – 0.10% (Wachendorf, 2008). It has to be noted that potassium and phosphorus is returned to soil when the ash is used for fertilisation of fields.

Calcium and magnesium increases the ash melting temperature (Beidermann, Obernberger, 2005). In our research, the amount of calcium in the grain of winter cereals was 0.37-0.48 g kg^{-1} (0.037-0.048%),

Table 3

Average grain chemical composition of winter cereals from the two-year trial period, g kg^{-1}

Species	N	P	K	Ca	Mg
Winter wheat	22.6	2.52	3.92	0.48	0.96
Triticale	20.4	2.98	5.08	0.43	0.83
Winter rye	20.9	2.78	4.06	0.37	0.55

Source: made by authors

Table 4

Grain ash and fibre content, and volume weight of winter cereals

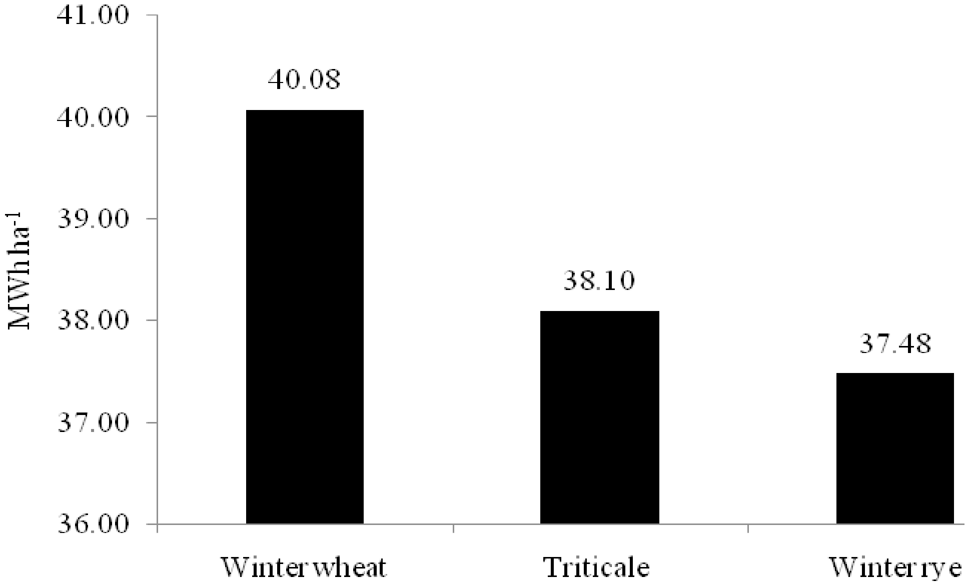
Species, variety	Ash, g kg^{-1}	Fibre, g kg^{-1}	Volume weight, kg m^{-3}
Winter wheat			
Skalmeje	16.20	25.38	771.0
line 99-115	16.48	28.75	778.3
Mulan	16.27	28.43	774.9
Average	**16.31**	**27.52**	**774.7**
RS/LSD $_{0.05}$	**0.29**	**1.32**	**11.19**
Triticale			
SW Valentino	19.87	27.43	683.5
Dinaro	18.63	24.91	688.9
line 0002-26	18.43	25.25	687.8
Average	**18.98**	**25.86**	**686.7**
RS/LSD $_{0.05}$	**1.16**	**1.15**	**7.19**
Winter rye			
Placido	15.70	21.73	732.1
Matador	16.23	22.86	725.6
Danskovij Nova	17.30	20.53	724.3
Average	**16.41**	**21.71**	**727.3**
RS/LSD $_{0.05}$	**0.73**	**2.36**	**4.63**

Source: made by authors

and the amount of magnesium was 0.55-0.96 g kg^{-1} (0.06-0.10%) (Table 3). The wood biomass contains more calcium (0.29 – 0.70%), while the amount of magnesium is lower (0.04 – 0.08%) (Wachendorf, 2008).

The ash content in biomass depends on its chemical composition. The chemical elements K, P, Si, Na, S, Cl, Ca, Mg, and Fe that are found in the grain, affect the ash content and the slag formation in the heating boilers (Beidermann, Obernberger, 2005). We determined that the ash content in the grain of winter cereals was 16.31 – 18.98 g kg^{-1} (1.63- 1.89%). This indicator is similar to the results of other researchers obtained in trials with winter cereals (Lewandowski, et al. 2003; Beidermann, Obernberger, 2005; Wachendorf, 2008). The highest amount of ash content was found in the grain of triticale: 18.98 g kg^{-1} (1.89%) on average. The ash content in the grain of winter wheat and rye was 16.31 and 16.41 g kg^{-1} respectively (1.63-1.64%) (Table 4).

According to the data found in the scientific literature the ash content of wood biomass is 0.4-0.8% (Obernberg, Thek, 2004); however, the biomass of willows and poplars contains 1.71-2.7% ash (Jenkins et al., 1998). The ash content of coal is 5 – 20%, depending on its quality (Biomass Energy..., s.a.). The European Union member states have elaborated standards for production of granules for heating. One of the indicators is the ash content of fuel. It has to be 0.7 – 1.5% (Garcia-Maraver, et al., 2011). The ash content obtained during the research slightly exceeded the EU standards for granules (Table 4). The ash content of examined varieties differed significantly ($p<0.05$). The varieties 'Skalmeje' and 'Mulan' had the lowest ash content among the winter wheat varieties – 16.20 and 16.27 g kg^{-1} (1.620 – 1.627%). For triticale



Source: made by authors

Fig.1. **The energy value of the heating value of winter cereal grain.**

the lowest ash content was observed in the grains of the variety 'Dinaro' and the line 0002-26, whereas for the winter rye it was 'Placido' (Table 4).

An important indicator for the choice of fuel is the volume weight that impacts the transportation and storage of fuel. According to the standards SS 187120 that have been elaborated in Sweden, the volume weight of the heating granules has to be from 600 kg m^{-3} (Obernberg et al., 2004; Garcia-Maraver et al., 2011). The volume weight of grains is similar to that of coal, namely, around 700 – 850 kg m^{-3} (Biomass Energy..., s.a.). According to our research data the volume weight of the grain of winter cereals was from 686.7 to 774.7 kg m^{-3}. Evaluating individual species, winter wheat has the highest grain volume weight, followed by rye and triticale (Table 4). No substantial differences were observed among the varieties.

An important indicator in the heating is energy value of the heating values. Out of all the species the winter wheat had the highest average energy value – 40.08 MWh ha^{-1}. The energy value of triticale and rye was slightly lower (for 4.9 and 6.5% respectively) (Fig. 1).

According to the data of literature, similar results have been obtained in the research in Germany (Nagel, 2000). The energy value of heating value, calculating from 1 ha, was different among the varieties of one species, depending on the grain yield. There was no substantial difference in the amount of yield acquired from different winter wheat varieties, while as regards triticale the variety 'Dinaro' provided the highest grain yield – 8.93 t ha^{-1}; thus the energy value acquired from 1 ha also increased up to 40.14 MWh ha^{-1} and was similar to the energy value ensured by wheat. As regards the winter rye, a substantially higher grain yield was acquired from the variety 'Placido' – 9.24 t ha^{-1}, thus the energy value from 1 ha was also high, namely, 42.87MWh ha^{-1}.

Conclusions

Evaluating different aspects related to the suitability of the grain of winter cereals for heating, it was found that winter wheat had the most appropriate indicators: highest average grain yield – 8.89 t ha^{-1}, heating value – 16084 kJ kg $^{-1}$, volume weight – 774.7 kg m^{-3}, energy value – 40.08 MWh ha^{-1}, and the lowest ash content – 16.31 g kg $^{-1}$. These indexes show that the grain of winter wheat provides a high-quality biomass for the heating purposes. However, good results were also acquired from certain winter rye and triticale varieties. As regards the chemical composition of the grain of winter cereals, a higher content of chemical elements (P, K) was found after the combustion in comparison to other types of plant biomass. The presence of these elements negatively affects the ash melting temperature that according to the scientific data results in slag formation in heating boilers. The research has to be continued.

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OILSEED RAPE (*BRASSICA NAPUS* SSP. OLEIFERA) SEED YIELD DEPENDING ON SEVERAL AGRO-ECOLOGICAL FACTORS

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Abstract

Most significant growing manner tool to gain high seed yield is the understanding about influence of different factors that have important role on winter oilseed rape growing. The lack of knowledge and research on different agro-ecological factors about oilseed rape growing is observed in Latvia. The aim of our research, started in the season of 2007/2008 and continued up to the season of 2010/2011 in Research and Study farm "Vecauce" of Latvia University of Agriculture, was to investigate the influence of agro-ecological factors (sowing date and rate, and fungicide as growth regulator) on seed yield of two types of winter rape cultivars. The observed seed yield results are analyzed in this paper. Rape was sown on five dates, starting with 1 August with ten days intervals. Specific four sowing rates were used in years 2007/2008 and 2008/2009: 120, 100, 80, and 60 germinate able seeds per m^2 for 'Californium' (line) and 80, 60, 40 and 20 germinate able seeds per m^2 for 'Excalibur' (hybrid). Equal sowing rates for both varieties were used in 2009/2010 and 2010/2011: from 120 to 20 germinate able seeds per m^2 with interval of 20 seeds per m^2. Fungicide as growth regulator (Juventus 90 s.c. (metconazole, 90 g L^{-1}) dose: 0.5 L ha^{-1}) was applied for rape plants at 4-6 leaves stage for crop sown on first three sowing dates. The highest average yield from all trial years was observed for variety 'Californium' sown on 10 August, and for variety 'Excalibur' F1 – sown on 20 August. Winter oilseed rape seed yield was significantly ($p<0.05$) affected by sowing date. The influence of sowing rate on yield was variable. Fungicide application significantly ($p<0.05$) increased the seed yield of 'Californium' in all trial years, but yield of 'Excalibur' – in three out of four trial years: 2008, 2010 and 2011.

Key words: winter oilseed rape, sowing date, sowing rate, fungicide as growth regulator, yield.

Introduction

Use of renewable energy resources is one of the core preconditions of sustainable development of rural areas. It is possible to obtain bioenergy from oilseed rape and agricultural by-products. Winter oilseed rape (*Brassica napus* ssp. oleifera) seeds are raw material for biodiesel production in Latvia. Winter form of crop is preferred because of the possibility of obtaining higher seed yield. Oilseed rape plant development could be affected by the growing manner including used cultivar, sowing date, application of growth regulators and agro-climatic factors. S.V. Angadi et al. (2003) reported that reducing plant population by half from 80 to 40 plants m^{-2} did not reduce seed yield when the reduced plant population was uniformly distributed. He also has recognized that oilseed rape exhibits plasticity to maintain seed yield across a wide range of populations. However, seed yield was generally increased, when sowing rate was increased and seed yield responses to the high rates of sowing or fertilizer only occurred where both inputs were at the highest level, indicating that the optimum level of one was dependent upon the level of the other input (Brandt et al., 2007). Optimal sowing date is still looked for in among the oilseed rape researchers and growers. Results up to now show that the impact of sowing date affected emergence, seedling vigour and yield (Gusta et al., 2004; O'Donavan et al., 2005). Sowing date influenced crop dry weight, crop height, branches, pod number and, after all, seed yield (Luthman and Dixon, 1987). Yield response to sowing date did not differ among similar types of cultivars in some experiments with canola (Clayton et al., 2004). O. Christen (1999) highlights that there is little variation in the date of sowing winter oilseed rape in Germany and the UK. The range is from the middle of August in the northern part of Germany and the UK, to the middle of September in southern Germany. He also reports that increasing the sowing rate does not compensate for late autumn drilling. Optimal sowing date for winter oilseed rape has to be determined in Latvia because of growing manner development and due to climate change.

Growth regulation with triazoles in autumn firstly provides a fungicide treatment, the effect of which on early Phoma (*Leptospheria* spp.) infections should not be underestimated. Secondly as well as growth regulation, combined with good nutrient application with potash and boron increases winter hardiness. Researches show that triazole is increasing the seed yield of rape depending on application timing (autumn or spring), and the increase was: from 0.04 to 0.55 t ha^{-1} respectively (Pits et al., 2008).

Substantial data about winter oilseed rape sowing date and rate, and fungicide application effect in autumn on winter oilseed rape yield in agro-ecological conditions of Latvia so far are little documented. Seed yield evaluation is part of our complicated research

Table 1

Soil parameters at trial site depending on year

Parameter	Year			
	2008	2009	2010	2011
pH KCl	7.4	7.2	7.2	6.7
available K, mg kg^{-1}	194	169	141	104
available P, mg kg^{-1}	115	100	111	111
humus content, g kg^{-1}	38	30	22	27

Source: made by the authors

on winter oilseed rape plant growth parameters. The aim of currently described section of our research was to investigate the influence of agro-ecological factors (sowing date and rate, and fungicide as growth regulator application) on two-type winter rape cultivars seed yield. Meteorological conditions as a factor are partly discussed. Part of data about this research has been already discussed in seminars and conferences, and described (Balodis and Gaile, 2010) using research data about yields in 2008, 2009 and 2010. After completion of the research in 2011 and data collection, analyses and conclusions are added in the current paper.

Materials and Methods

To achieve the defined aim, the four year (starting from 2007/2008 to 2010/2011) experiments were carried out in the Research and Study farm "Vecauce" (latitude: N 56º 28´, longitude: E 22º 53´) of Latvia University of Agriculture. A three-factor field trial was established using two types of winter rape (*Brassica napus* ssp. oleifera) cultivars (line 'Californium' and hybrid 'Excalibur' both bred by Monsanto Crop Science – DEKALB). The following factors were investigated:

Factor A – sowing date: A1 -1st – called 1st August, A2 - 2nd – called 10th August, A3 - 3rd – called 20th August, A4 - 4th – called 1st September, A5 - 5th – called 10th September.

Factor B – sowing rate (B1-120, B2-100, B3-80, B4-60 germinable seeds per m^2 – 'Californium'; B1-80, B2-60, B3-40, B4-20 germinate able seeds per m^2 – 'Excalibur' in 2007/2008 and in 2008/2009. In seasons 2009/2010 and 2010/2011, sowing rates were supplemented to equals - B1-120, B2-100, B3-80, B4-60, B5-40, B6-20 germinable seeds per m^2 for both varieties.

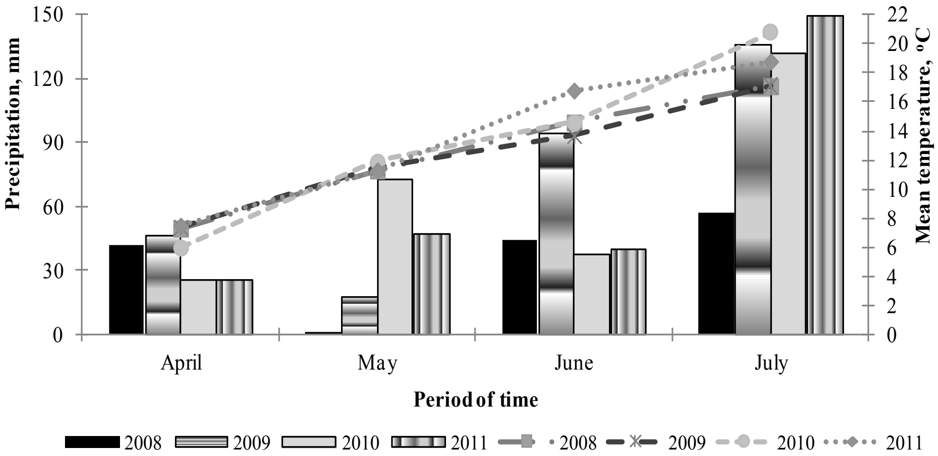
Factor C – fungicide application (C1 – control, without fungicide; C2 - fungicide applied as growth regulator). Fungicide application scheme: 0.5 L ha^{-1} of fungicide Juventus 90 s.c. (metconazole, 90 g L^{-1}) was applied at the 4-6 leaves stage:

- on rape sown on 1st August –30th August 2007, 8th September 2008 and 2009, 9th September 2010;
- on rape sown on 10th August – 12th September 2007, 13th September 2008, 22nd September 2009, 24th September 2010;
- on rape sown on 20th August – 27th September 2007, 8th October 2008, 30th September 2009, 7th October 2010.

Soil at the trials' site was strongly altered by cultivation in 2008 and 2011 and soil-gleyic in 2009 and 2010. Soil parameters were slightly different depending on year (Table 1).

Traditional soil tillage with mould-board ploughing was used, rototilling was performed before sowing. The crop was fertilized with a complex mineral fertilizer at the rate of N 12 to 28 kg ha^{-1}, P 18 to 30 kg ha^{-1}, and K 79 to 103 kg ha^{-1} before sowing depending on a year and soil properties. Top-dressing with nitrogen fertilizer at the rate of 70 kg ha^{-1} of N (ammonium nitrate) - at the start of vegetation, plus 70 kg ha^{-1} of N (ammonium sulphate) - at the stage of well developed rosette, was applied. Sowing was done close (with one or two days deviation) to established dates; deviations in some occasions occured because of inappropriate (mainly too moist) soil conditions for sowing. Weeds were controlled using herbicide Butisan Star s.c. (metasachlor, 333 g L^{-1} + kvinmerac, 83 g L^{-1}), 2.5 L ha^{-1} in 2007-2009, and 3.0 L ha^{-1} in autumn 2010. Herbicide was applied when the oilseed rape was fully germinated in plots of first three sowing dates in 2007 and 2008, and directly after sowing in 2009 and 2010 for all trial. For plots of 4th and 5th sowing date, herbicide was not used in autumn 2007 (Lontrel 300 s.c. (clopiralid, 300 g L^{-1}) 0.5 L ha^{-1} was used in spring 2008). To decrease the possible impact of *Sclerotinia* stem rot (*Sclerotinia sclerotiorum*) incidence, fungicide Cantus d.g. (boscalid, 500 g kg^{-1}) 0.5 kg ha^{-1} was used during full flowering (GS 65). Two-factor analysis of variance was used for processing the experimental data.

Summarizing meteorological conditions of research years, it is clearly obvious that autumn meteorological conditions were different depending on year and had a significant impact on plant autumn development. Serious research results about plant autumn growth depending on meteorological conditions have already been published (Balodis, Gaile, 2011). Unusually very long autumns and warm winters were observed



Source: made by the authors

Figure 1. **Amount of precipitation and mean air temperatures in RSF "Vecauce" in vegetation periods 2008 -2011.**

in research years 2007/2008 and 2008/2009. October 2009 and 2010 characterizes with very low mean air temperatures. Comparatively harder winters with lower mean temperatures and much thicker and stable snow cover were observed in years 2009/2010 and 2010/2011.

Winter conditions had critical influence to plant survival on spring in all years. Meteorological conditions in trial year's autumns were considerably different. October 2009 and 2010 characterizes with very low mean air temperatures. Unusually long-lasting autumns and warm winters (2007/2008 and 2008/2009) were observed for both research years. Vegetative growth period from April to July (full ripening period) were also different on temperatures and precipitation (Fig. 1).

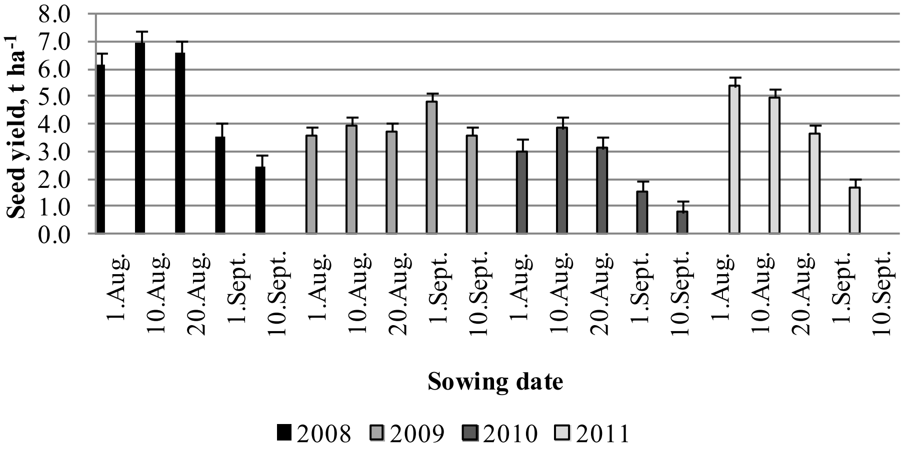
Weather conditions in April were quite similar in all trial years, and vegetation started on 1st of April in 2008 and 2010, 3rd of April in 2009, and on 5th of April in 2011. An extremely dry May was observed in years 2008 and 2009, but oil-seed rape plants used the moisture reserves suspended in soil during winter, and growth and development of crop occurred without irregularities. Precipitation in June was close to long–term observations (51 mm), with much higher precipitation in year 2009. Extraordinarily, but precipitations in July in three out of four trial years were much higher than long–term observations (75 mm). Heat wave during July in year 2010 was noted, but that with high precipitation was very favourable conditions for oilseed rape yield formation.

Results and Discussion

Sowing date influence. From the four-year results (2008-2011), it was evident that winter rape seed yield was influenced by the sowing date, which agrees with other research results (Boelcke et al., 1991), as well as by the sowing rate and fungicide application in autumn period. Meteorological conditions in autumn and summer season were different in each trial year. Significant impact ($p<0.05$) of sowing date was observed on the seed yield in all trial years for both varieties – 'Californium' and 'Excalibur'. On average (when the following sowing rates were used: 120 to 60 germinable seeds per m^2 – 'Californium'; 80 to 20 germinate able seeds per m^2 – 'Excalibur') highest seed yields were observed in year 2008, because of appropriate meteorological conditions in autumn despite the comparatively dry summer (see Figure 1). As winter 2010/2011 was unfavourable for small, immature plants (sown on 10th of September), the plants did not survive at all. Highest yields for each cultivar were achieved in different sowing dates. Average highest seed yield for line variety 'Californium' was obtained from plots sown on 2nd sowing date (10th of August) on years 2008 and 2010, in 4th sowing date (1st of September) in year 2009, and on 1st sowing date (1st of August) in year 2011 (Fig. 2).

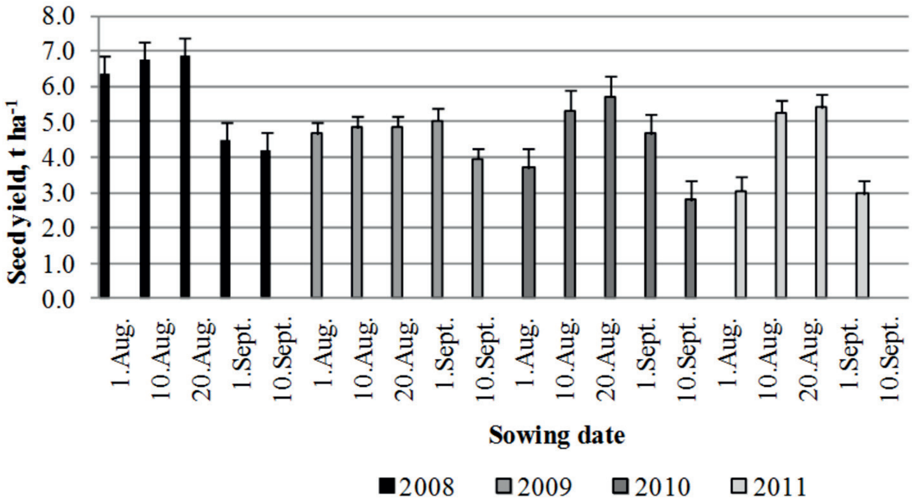
There were no significant differences in seed yield of 'Californium' when sown on 10th and 20th of August in 2008 and when sown on 1st and 20th of August and 10th of September in 2009. Also no significant difference was observed between the seed yields, obtained from plots sown on 10th and 20th of August in year 2009. In 2010 significant yield differences were not observed between plots on 1st and 20th of August, but in 2011 all yield differences depending on the sowing date were significant (Fig. 2).

Hybrid cultivar 'Excalibur' (Fig. 3) yielded the most on 3rd sowing date (20th of August) in years 2008, 2010 and 2011, but on 4th sowing date (1st of September) in year 2009. There were no significant differences in the seed yields for 'Excalibur' sown on 10th and 20th of August and 1st and 10th of September in year 2008, between that sown on 10th and 20th of August in 2010 and 2011. Interesting that seed yields in some



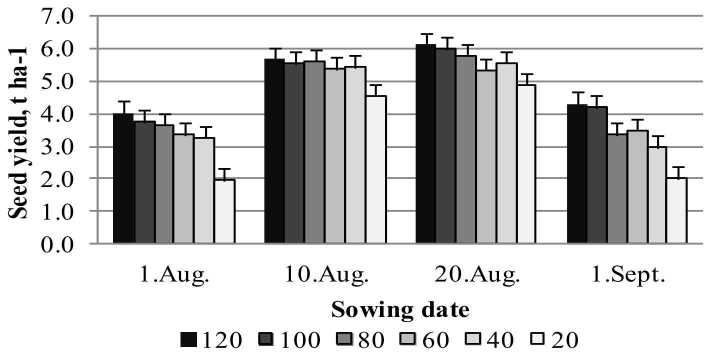
Source: made by the authors

Figure 2. **The effect of sowing date on winter oilseed rape seed yield for variety 'Californium' in years 2008-2011 ($p<0.05$).**



Source: made by the authors

Figure 3. **The effect of sowing date on winter oilseed rape seed yield for variety 'Excalibur' in years 2008-2011.**



Source: made by the authors

Figure 4. **The effect of sowing rate on winter oilseed rape seed yield of cultivar 'Excalibur' in year 2011 (plots sown on 10th September did not overwinter).**

cases were similar in plots sown on 1st of August and 10th of August (Fig. 3). Also it is clearly observed that seed yield from plots sown on 1st of September 2009 was not significantly higher than that obtained from plots sown on previous two sowing dates (10th and 20th of August), which is in accordance with hybridization benefit of hybrid cultivars which are more suitable for later sowing. Also 'Excalibur' sown later yielded better if compared with 'Californium' (Figs. 2 and 3).

From four trial years it is difficult to define the optimal sowing date, because of variable results, but if results are expressed on average from all trial years then the highest yield was observed for cultivar 'Californium' (line) sown on 10th August and for cultivar 'Excalibur' (F1) – sown on 20th August.

Sowing rate effect. Plant density (sowing rate – factor B) has a significant role in yield formation for winter oilseed rape (Sierts et al., 1987; Butkute et al., 2006). It is similar to our results of sowing rate effect on seed yield. The highest seed yields were gained with relatively highest sowing rates (actual plant densities at harvest are not considered in current paper) in our experiment. For 'Californium' on average 120 germinable seeds per m^2 yielded most in all trial years and 80 germinable seeds per m^2 in years 2008 and 2009, but for 'Excalibur' it is interesting that on average 120 germinable seeds per m^2 yielded the most in years 2010 and 2011 (Fig. 4), when equal sowing rates were used (see section Materials and Methods).

Results with 'Excalibur' showed that sowing rate and plant density have to be more analyzed as a very important yield formation factor and yield structural element, e.g., in 2011,the importance of sowing rate was more marked in sowing dates which influenced the yield mostly - 1st of August and 1st of September. Plants sown on 1st of August showed tendency to overgrow - exceeded plant biometrical parameters for successful wintering were noted. However, sowing rate had insignificant ($p>0.05$) impact on seed yield in two out of four years – 2008 and 2011 for 'Californium', and in year 2010 for 'Excalibur'.

Fungicides effect. The four-year trial results (2008-2011) we suggest that winter oilseed rape seed yield was influenced by fungicide application in autumn period, and the effect of fungicide application in its turn depended on sowing date and sowing rate. Seed yields were positively affected because fungicide application probably improved plant overwintering and also decreased disease incidence level in autumn period. Such observations agree with the literature data (Leach et al., 1994; Butkute et al., 2006). We have already analysed the fungicide application effect on plant biometrical indicators in our previous research (Balodis, Gaile, 2011a). Higher yields caused by fungicide application for each variety were achieved in different sowing dates, and in few cases fungicide application had no positive effect on the seed yield (Table 2). Plant growth regulation is expected to give a greater effect on plant biometrical parameters which causes seed yield increase mostly in early sowing dates – 1st of August in our experiment. The seed yield was affected by fungicide treatment in all trial years, and mainly we obtained the expected result that seed yield increased. Nevertheless, an exception was noted when rape was sown on 1st of August in 2009 for both varieties and for 'Excalibur' sown on 10th of August in years 2009, 2010 and 2011, and on 20th of August in 2009, 2011 (Table 2). Fungicide application had a statistically significant impact on the average seed yield in all trial years for both varieties; an exception was for 'Excalibur' in year 2009, but still tendency of yield increase was observed in two sowing dates (Table 2).

Interesting that fungicide positively affected the seed yield for 'Excalibur' that was sown as early as on 1st of August because that sowing date is untimely or overly early for a hybrid cultivar. So that discovers oilseed rape growers much larger variability to get higher seed yields, because use of a hybrid variety in combination with growth regulation

Table 2.

Fungicide effect on average seed yield (t ha^{-1}) depending on sowing date in years 2008-2011

Variety	Sowing date	2008		2009		2010		2011	
		C1†	C2‡	C1†	C2‡	C1†	C2‡	C1†	C2‡
Californium	1st August	6.16	7.15	3.61	3.49*	3.02	4.11	5.37	5.54*
	10th August	6.93	7.87	3.97	4.17	3.85	3.80*	4.97	5.27
	20th August	6.60	7.37	3.75	4.37	3.14	3.59	3.67	4.08
Excalibur	1st August	6.38	6.77	4.66*	4.25*	3.71	5.66	3.06	4.39
	10th August	6.97	7.75	4.83*	4.85*	5.33	5.04*	5.25	5.13*
	20th August	6.38	6.77	4.86*	5.59*	5.71	6.65	5.40	5.43*

C1†- control; C2‡ - fungicide treated plants; *$p>0.05$, when C1 and C2 are compared within the same sowing date in a definite year;

Source: made by the authors

possibilities gained higher yields in three out of four trial years.

Conclusions

Significant impact ($p<0.05$) of sowing date was observed on the seed yield in all trial years for both varieties – line type 'Californium' and hybrid type 'Excalibur'. Highest yields for each variety were achieved in different sowing dates, but on average from all trial years the highest yield was observed for 'Californium' sown on 10th August and for 'Excalibur' F1 – sown on 20th August.

The highest seed yields were gained with highest sowing rates. In the present experiment, plots sown at rate of 120 germinate able seeds per m^2 on average yielded the most in all trial years for 'Californium' and for 'Excalibur' - in 2010 and 2011, but 80 germinable seeds per m^2 in years 2008 and 2009 for 'Excalibur'. Sowing rate and plant density have to be analyzed more in detail as very important yield formation factors and yield structural elements.

Higher yields caused by fungicide as growth regulator application in autumn for each variety were achieved when sown in different sowing dates, but mainly when sown until 20th of August. Later sown rape did not reach the sufficient development stage for fungicide application. In some cases fungicide application had no positive effect on seed yield. Positive effect of fungicide application has to be analysed in combination with plant biometrical parameters in autumn and overwintering results.

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COMPARISON OF DIFFERENT ENERGY CROPS FOR SOLID FUEL PRODUCTION IN LATVIA

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Abstract
Linseed and fibre flax (*Linum usitatissimum* L.), hemp (*Cannabis sativa* L.), sunflowers (*Helianthus annuus* L.) and reed canary grass (*Phalaris arundinacea* L.) are grown in Latvia, and these bioenergy crops can be used for the production of solid fuel. Some oilseed crops have large perspective for biofuels. Sunflowers, canary seed and hemp have large biomass, but flax and sunflowers have high calorific value. The ash content is quite high in all plants sheave. Linseed can be used not only for obtaining linseed oil, but also for obtaining solid fuel (briquettes, linseed pellets) from straws. Within the framework of this research 2 sunflower varieties, 11 oil and 3 fibre flax samples, 2 reed canary grass varieties and 10 varieties of hemp 2009 and 2010 were studied in the years. The aim of the research was to evaluate the variety of plant biomass qualitative properties for production of solid fuel. All of these bio-energy plants were studied for the following parameters: biomass content, moisture content of dry matter, ash content of dry material, calorific value, sulphur and chlorine content. The quantity of plant biomass yield depends on many factors. Harmful substances in almost all plants make approximately from 0.15 to 0.22% of dry matter. The average highest calorific value at V=const for dried fuel at 105ºC of sunflower dry matter was 20.6 MJ·kg^{-1}, and of fibre flax - 18.5 MJ kg^{-1}. The growing of hemp is beneficial to the environment, and hemp is also a good resource as a biofuel. By choosing suitable plants, high dry matter biomass solid fuel products can be obtained.
Keywords: energy crops, dry matter, calorific value, ashes.

Introduction

Biofuels represent a potential means to reduce carbon emissions, reduce dependency on increasingly expensive fossil fuels, and provide working places for the local economy. Biofuels can be used as feedstock for production of liquid fuels or for solid fuel for direct combustion for heating. Biomass is a unique fuel and has the potential to play a significant role in the future energy. Unlike other renewables, biomass can provide continuous electricity generation, and is the only widespread source of renewable heat. Increased use of biomass as a source of energy (electricity and heat) will contribute to the reduction of CO^2 emissions, increase energy security, and support sustainable development and regeneration of rural areas (Bridgeman et al., 2008).

Power plants set demanding requirements regarding the biomass properties which include the total ash content, the melting behaviour, and the chemical composition. Compared to coal, biomass contains less ash, but a greater amount of alkaline metals in the ashes, which are usually responsible for fouling heat transfer surfaces (Poiša, Adamovičs, 2011).

At present the meadows and pastures of Europe, which up to now guaranteed feed stocks for animals; fulfil new functions as environmental stabilizers and as an additional option for renewable energy resources, also forming new directions for research in the cultivation of plants (Кулаковская et al., 2010).

Some oilseed crops have large perspective **excess** to biofuels. The ash content is quite high in all plants sheave. Linseed can be used not only for obtaining linseed oil, but also for obtaining solid fuel (briquettes, linseed pellets) from straw. Reed canary grass is used for production of fuel briquettes and granules (Adamovičs et al., 2007; Lazdiņa et al., 2008). In their burning process from reed canary grass less harmful emissions are produced: carbon dioxide that comes into atmosphere does not influence the balance in the nature and does not increase the greenhouse effect if compared to the effects created by fuel oil or petrified fuel heating (Tardenaka, Spince, 2006). In 2006, Latvia exported about 500 thousand tons of granules, which is one of the largest indicators in Europe (Adamovičs et al., 2007). In other countries, for instance, in Finland and Sweden, canary briquettes are made in industrial amounts (Sanderson, Adler, 2008; Lazdiņa et al., 2008; Tardenaka, Spince, 2006).

Hemp is grown for production of hemp oil as for as for obtaining of hemp fibre. In both cases there appears excess. In the process of oil production these are stalks, but in the process of fibre obtaining sheave. This excess can be used in the fuel production. The features of hemp stalks have a large resemblance to the characteristics of wood-pulp. There are cellulose and lignin both in the hemp stalks and in wood-pulp, and the calorific value of stalks is the same as of wood-pulp, and in the burning process less ashes are produced. By briquetting or making granules of hemp stalks, good solid fuel can be produced. Hemp with its energy qualities - the high thermal capacity and relatively large dry matter yield (DM yield) – is a good source material for the production of energy, especially, if it is utilised mixed with other energy source materials (Mańkowski, 2003).

There is relatively little dry mass in sunflower green mass (Adamovičs et al., 2007). The environmental conditions in our research were different each year.

Reed canary grass (*Phalaris arundinacea* L.) is a tall-growing, perennial grass which is widely distributed across Europe and other northern countries. Reed canary grass is better adapted to diverse uses and environmental conditions than most other commonly used perennial grasses. The stems can reach 2.5 m in height (Lazdiņa et al., 2008). Comparing the reed canary grass grown in Latvia according to the chemical content, it can be seen that it contains more alkali metals than other energy crop plants, which is not desirable when used for biofuel production (Biedermann, Obernberger, 2005). Reed canary grass is being cultivated in northern Europe as a biofuel and about 10.000 acres are in production in Scandinavia (Kätterer et al., 1998).

One of the most important quality indicators of fuel material is ashes. Ashes are those mineral substances that remain after the burning of fuel (Белосельский, Соляков, 1980; Cars, 2008) or, in other words, these are non-organic substances. However, big amounts of ashes create problems of automatization of burning processes for consumers (Tardenaka, Spince, 2006).

Energy crops are widely used in various sectors of the economy. They also have a positive effect on the environment, they reduce soil erosion and contamination with chemical substances, and they can be grown in soil which cannot be used for food crops (Poiša et al, 2011; Sanderson, Adler, 2008; Wrobel et al., 2009).

Energy crops have different demand for quality than food and agricultural plants. Heat supply and energy obtaining should be effective, accessible and nature-friendly, which is possible by using the renewable energy resources. The aim of the research was to evaluate the variety of plant biomass qualitative properties for production of solid fuel.

Materials and methods

Energy crops hemp (*Cannabis sativa* L.), fibre flax and linseed (*Linum usitatissimum* L.), sunflower (*Helianthus annuus* L.) and reed canary grass (*Phalaris arundinacea* L.) – were tested in the following locations and under the conditions described in Table 1. Soil type for all plants was the humi-podzolic gley soil.

Meteorological conditions. The climate of Latgale varies somewhere between maritime and continental and in general is favourable for many cultures growing. The harvesting conditions were good in 2009-2010. There were no dramatic temperature deviations, and also precipitation was quite good for sunflower growing.

The air temperature from April to August in the plant growth period was greater than the long-term average, except for September. During April, July and August the precipitation was less than 50% of the long-term average indicators. In June the rainfall amount was 75.7 mm, while the long-term average indicator was 75 mm. During May and September the rainfall amount was near the norm.

The following parameters were tested:

- the moisture content - according to standard LVS EN 14774,
- the ash content for dry material - according to standard LVS EN 14775,
- the gross calorific value at V=const for dried fuel at 105ºC - according to standard LVS EN 14918,
- the net calorific value at V=const - according to standard LVS EN 14918,
- the ash melting behaviour oxidizing atmosphere - according to standard LVS CEN/TS 15289.

The trial data were processed using correlation and variance analyses of two and three factors (ANOVA) and descriptive statistics. The means are presented with their LSD test. Representative average samples of the indicators were used in the calculations.

Results and discussion

Biomass fuel, the same as fossil fuel, has four important properties: the thermal capacity, the chemical properties, the physical properties, and the combustion properties (Magasiner, van Alphen, Inkson et al., 2002).

Within the framework of this research all varieties (Table 1) in the 2009 and 2010 were studied years.

Growing fibre flax in Latvia conditions, on average 7.3 t·ha^{-1} of straw yield can be obtained, 2.5 t·ha^{-1} is fibre and 4.8 t·ha^{-1} is shove (Fig.1). From linseed three times less straw yield can be obtained on average 2.07 t·ha^{-1}; from this amount on average 1.3 t·ha^{-1} are sheave. The earlier hemp varieties 'Bialobrzeskie', 'Beniko', 'Epsilon 68', 'Fedora 17', 'USO 31' and 'Fenola' were studied. In Latvia, the varieties 'Epsilon 68', 'Fedora 17' and 'Santhica 27' reached the height of more than 2 metres, but the height of more than 2.5 metres were reached by later sorts - 'Felina 32' and 'Futura 75', which means that tall plants can be grown in Latvia climate conditions (Пойша, Адамович, 2011). The height and development of hemp plants is largely dependent on temperature conditions (Давидян, 1979). The height of hemp is also influenced by the vegetation year and the quota of nitrogen fertilizer (Poisa, Adamovics, 2010). In Latvia, 14.0 t·ha^{-1} of biomass for solid fuel can be obtained from 2.5-3.5 m tall hemp, from this amount on average 8.9 t·ha^{-1} are sheave.

Sunflower was 12.3 t ha^{-1} dry biomass yields, but other than seeds and leaves sunflower was 8.7 t ha^{-1} sheave yields.

In Latvia, up to 7-10 t ha^{-1} of dry biomass yield of reed canary grass can be obtained (4-8 t ha-1 of dry biomass in loam, and up to 10 t ha^{-1} in peat soil). The variety 'Bamse' was created by Swedish breeders particularly for the needs of bioenergy (Poisa, Adamovics, 2010).

Table 1

Trials' methods in 2009-2010

Plants	**Fibre flax** (*Linum usitatissimum* L.)	**Linseed** (*Linum usitatissimum* L.)	**Hemp** (*Cannabis sativa* L.)	**Sunflower** (*Helianthus annuus* L.)	**Reed canary grass** (*Phalaris arundinacea* L.)
Soil composition	pH_{KCl} = 6.4-7.0; OM, % = 3.0–3.5%; P_2O_5 = 130-145 mg kg^{-1} K_2O = 118–124 mg kg^{-1}	pH_{KCl} = 6.4-7.0; OM, % = 3.0–3.5%; P_2O_5 = 130-145 mg kg^{-1} K_2O = 118–124 mg kg^{-1}	pH_{KCl} = 7.0-7.3; OM, % =3.8 (Turin's method); P_2O_5 = 83-145 mg kg^{-1} ; K_2O = 65-118 (DL method)	pH_{KCl} = 6.4-6.7; OM, % = 3.0–3.5%; P_2O_5 = 85 mg kg^{-1} K_2O = 118–124 mg kg^{-1}	pH_{KCl} = 5.8; OM, % =5.2%; P_2O_5 = 85 mg kg^{-1} K_2O = 90 mg kg^{-1}
N:P:K fertilizers	N:P:K 6:26:30, 300 kg ha^{-1}	N:P:K 5:10:25, 400 kg ha^{-1}	N:P:K 6:26:30, 300 kg ha^{-1}	N:P:K5:10:25 120 kg ha^{-1}	N:P:K 5:10:25, 400 kg ha^{-1}
Sowing time	5 th May	7 th May	4th May-2009; 13rdMay-2010	May 13 -2009 May 13 -2010	12th August -2008; 29th April - 2009
Seeding rate kg ha^{-1}			60-70 kg ha^{-1}	20-30 kg ha^{-1}	70 kg ha^{-1}
Sort or/and varieties	'Ošupes 31' 'Ošupes 30' 'Vega 2'	'37-1'; '37-2'; '37-5'; '37-9/1'; '37-10/1'; '37-28'; '37-34'; '37-49'; '37-50'; '38'; 'ST Lirina'.	Bialobrzeskie Beniko, Epsilon68 Fedora17 Felina32 Santhica27 Futura75 USO31 Finola	'Alyssa' 'Pacific'	'Marathon' 'Bamse'
N fertilizer rate	15 g m^{-2} N	30 g m^{-2} N	N0, N60, N100	N0, N60, N120	N0, N30, N60, N90
Harvesting time	4th September-2009	29 th August	21 st September-2009 14th September-2010	20th September-2009 15th September-2010	6th October

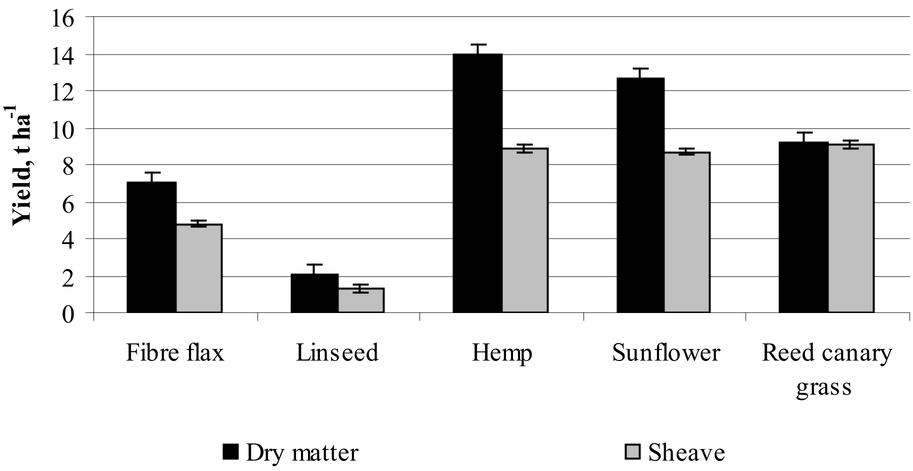

Figure 1. **Average dry matter yield of all species, t ha^{-1} (2009-2010). (average from all varieties and harvest dates)**

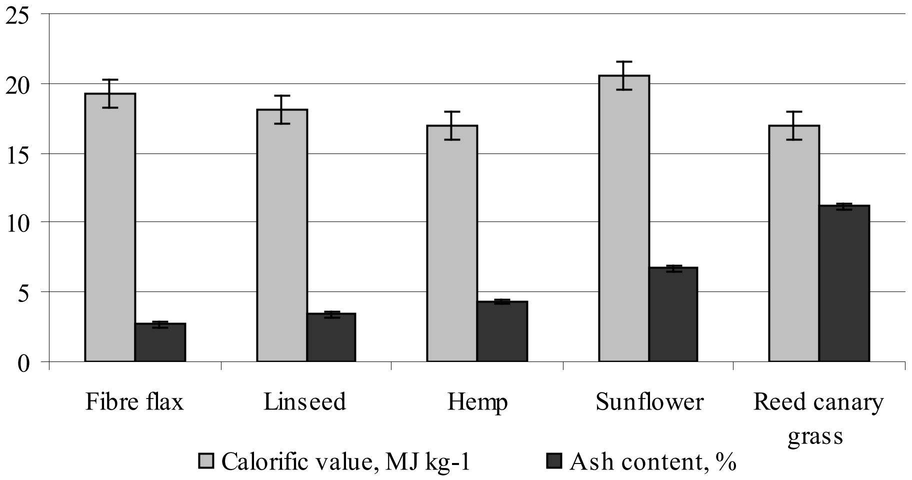

Figure 2. **Average calorific value and ash content in all species dry matter, MJ·kg^{-1}.**

Irrespective of other negative results, sheave of flax, hemp and sunflower has a great calorific value. Hemp stems are used as a fuel, and its average calorific value was 16.98 MJ·kg^{-1} ± 0.5%, which is less than for oil and fibre flax (average calorific value - 18.1-18.05 MJ·kg^{-1}), but the calorific value of flax sheave grown in some other countries varies between 16.9 – 17.8 MJ·kg^{-1}± 0.5%. That highest calorific value at V=const for dried fuel at 105ºC of sunflower straw sheaves was 16.5 MJ·kg^{-1} ± 0.5%, but that of sunflower husk – 25.02 MJ·kg^{-1}± 0.5% (average calorific value was 20.8 MJ·kg^{-1}± 0.5%). The calorific value of reed canary grass was 16.8 MJ·kg^{-1} and 17.1 MJ·kg^{-1} for spring yield that has a little difference from the flax and hemp calorific value.

The ash content is one of the major qualitative characteristics of biomass or plant sheave. The ash content of all plant sheave must be up to 3%. The ash content should not surpass 5-7% under the conditions of correct stockpile. Nevertheless, the experience shows that the ash content can reach even 20%. The ash content of the energy crops was very different and ranged from 3.1 to 12.8% (Fig.2). The average ash content of the flax shove of fibre flax wa 2.7 ± 0.1% and of the flax chaff was 4.9 ± 0.1%. Ash content in hemp shoves exceeds the norm, and in our studies it reached approximately 4.3 ± 0.1%, which is for 0.8 % higher than in linseed and for 2.4% less than in sunflower. The average ash content of the stem in 2009 was higher than in the shoves (Kymäläinen et al., 2004). Ash content in sunflower straw was 6.7 ± 0.1%. Ash content is high in the sunflower heads combustion – 7-8.5 %. It two times exceeds the norm, thus sunflower sheave has much surplus of ashes that can be used as soil fertilizer, if burnt in big stoves.

The ash content in reed canary grass was 9.5-12.8 ± 0.1%. The smallest ash content (on average 11.9 ± 0.1%) was found in variety 'Marathon' which was sown in August, 2008. In comparison with varieties that were sown in 2009 it is seen that variety 'Bamse' has a higher ash content – on average 15.4 ± 0.1%. In our research, the ash content of reed canary grass varieties sown in 2009 was two times higher than reported in other studies (Poiša et al., 2010).

Straw of energy crops can contain comparatively large amount of chlorine and sulphur which have a significant relationship for corrosions and sediment formation. The standard amount of sulphur (according to data of LVMI Silava) is from 0.1 to 0.2% (Lazdiņa, Lazdiņš, Bārdulis et al., 2008). The lowest amount of sulphur and chlorine was in linseed (0.03-0.1± 0.05%), that covers the norm, but the highest content of sulphur was in reed canary grass and it reached 0.245-0.259 ± 0.05% (Platače et al., 2011). The amount of sulphur in reed canary grass was surpassed. Reed canary grass will respond to nitrogen fertilization and to a less extent to potassium and phosphate fertilization (Poiša et al., 2011). Sunflowers contain higher percent of Cl – 0.2 ± 0.05%, but the content of sulphur is two times lower than that of chlorine. The content of sulphur ranges from 0.08 to 0.1 ± 0.05%. Variety 'Alyssa' with a fertilizer dose N120 contains less chlorine (Komlajeva et al., 2011).

Conclusions

Among all studied plants (fibre flax, linseed, hemp, sunflower and reed canary grass), hemp had the highest yield of biomass. Yield at the same climatic conditions depends on the variety, soil type, fertilizer, plants and other factors.

The highest calorific value at V=const for dried fuel at 105ºC of sunflower dry matter was 20.6 MJ·kg^{-1}, which is 2% higher than in hemp and canary, and 1.3 % higher calorific value than in flax.

For production granules and briquettes the varieties with high content of carbon and low amount of ashes should be chosen. Low ash content was in the shove of fibre flax and linseed, but the highest ash content was in reed canary grass (*Phalaris arundinacea* L.), which has a negative sign for solid fuel. The resulting ash quantity in the trials was larger than the permitted, so only hemp can be used as an addition for briquette and pellet production. It is stated that the difference of ash content among one group of plants is insignificant.

Energy crops hemp (*Cannabis sativa* L.), sunflower (*Helianthus annuus* L.) and reed canary grass (*Phalaris arundinacea* L.) – may be an ideal biofuel source, but reed canary grass have a large ash content, which makes it impossible.

In Latvia, the sulphur content for the growing energy crops ranges from 0.1 % to 0.2 %; from the studied energy plants, fibre flax, linseed, hemp and sunflower correspond to the norm of the sulphur and chlorine amount. The plants which biomass is higher than 4 t ha^{-1} and which have lower content of ashes and chemical elements can be suitable for the solid fuel production.

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MAIZE PRODUCTION FOR BIOGAS IN LATVIA

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Abstract
Anaerobic digestion is becoming more popular in producing biogas. Nowadays biogas production is traditionally based on biomasses such as manure, sewage sludge and industrial waste, but during recent years, in many countries, the use of energy crops as agricultural substrate has increased. One of the most used substrate for biogas production in European countries is maize. Researchers have mentioned that key factors for a maximum biogas yield from maize are selected hybrid, time of harvesting, type of conservation and pretreatment of the biomass. Also the nutrient composition of the energy crop is important. The paper aimed to evaluate impact of hybrid, harvest time and agro-meteorological condition on maize biomass production for biogas. A field trial was carried out in the Research and Study farm "Vecauce" of the Latvia University of Agriculture (LLU) from 2008 till 2011. Ten (in 2008), eleven (in 2009) and fifteen (in 2010 and 2011) maize hybrids with different maturity ratings according to FAO numbers (FAO 180–340) were harvested at three different times beginning on 5 September at fourteen-day intervals. Composition of fresh maize was analyzed for all hybrids using standard methods. Results were statistically analyzed using analysis of variance, correlation and descriptive statistics. Results showed that harvest time effect on maize organic dry matter (ODM) content and yield was substantial ($p<0.05$) in all years. The highest average ODM yield in all years was reached when maize was harvested at the last harvest time. The influence of maize hybrid, vegetation period and hybrid on average ODM yield was substantial ($p<0.05$).
Key words: maize hybrid, yield and organic dry matter.

Introduction

The main reason for the development of renewable energy is the environment, especially in relation to global climate change and the need to improve security and diversity of energy supply. The biogas production has positive impact on the environment since less CO_2 is formed during combustion than it is used for photosynthesis by plants from which it is produced (Vindis et al., 2009). Renewable technologies create job-places using local resources in a new "green" industry in many countries of the world. Rapid growth of the number of biogas plants accelerates the search for a suitable substrate for biogas production. Biogas production is a key technology for the sustainable use of agricultural biomass as a renewable energy source. Production of methane – rich biogas through anaerobic digestion of organic materials provides a clean and versatile form of energy. In a biogas plant, each group of substrates has a specific potential for biogas production. The best properties are raw-harvested plant material with low lignin content (Klimuik et al., 2010).

Biogas production from energy crops is of growing importance. Biogas production has higher demands for arable land, assets and work than other forms of renewable energy production. Therefore, economic efficiency must be given particular attention. Economic biogas production requires high biogas yields (Ress et al., 1998). Fifteen biogas plants are operating now in Latvia. The produced biogas is used for electricity co-generation. Most of the existing agricultural biogas plants are operating with maize substrate.

Energy crops used for biogas production should provide high organic dry matter yield and high methane output per hectare. Most suitable crops are those rich in easily degradable carbohydrates (Heiermann et al., 2009). The literature indicates that maize may be suitable for biogas production because it has the highest biomass yield potential of all field crops grown in Central Europe. Maize is yet the most dominating crop for biogas production in Europe (Cus et al., 2009). Also for agroecological condition of Latvia, maize can be suitable having high annual organic dry matter yield per hectare, and optimal for ensiling dry matter content. Several factors can affect biogas yield from maize substrate. Key parameters affecting biogas yield investigated so far, are the maize variety, time of harvesting, mode of conservation, and pre-treatment of the biomass prior to the digestion process (Amon et al., 2007). As crop growing season and plant developmental stage at harvest are other important factors that influence the forage quality of maize (Darby and Lauer, 2002), then we can predict that the same factors can affect also quality of maize as biogas substrate. The increasing use of maize as a biogas substrate raises questions concerning the morphology and chemical composition of the ideal maize (Schittenhelm, 2008). Maize is a crop with a rapid growth rate that yields best under moderate to warm temperatures. Cool temperatures slow down the progress to maturity, and high temperatures hasten maturity (Brown, 1997). The organic dry matter (ODM) content is an important factor influencing the microbial population and activity during ensilaging.

Many problems that are still unresolved are pointed out in the fields of harvest time optimization, and assessment of energy maize production with respect to C and N flows at system level (Herrmann et al., 2006). In Latvia some investigations about harvest time influence on maize yield and quality were made before, but with typical forage maize hybrids (Gaile, 2010). Also results of our investigations on harvest time influence on maize OMD yield using other hybrids are previously partly published and reported during a scientific seminar (Bartuševics, Gaile, 2010), but in this paper new results of two additional years are included and outcome of all four research years' period is analyzed.

The paper aims to evaluate the impact of hybrid, harvest time and agro-meteorological conditions on maize biomass production for biogas

Materials and Methods

A three-factor field trial was carried out during 2008-2011 in the Research and Study farm "Vecauce" (latitude: N 56° 28´, longitude: E 22° 53´) of the Latvia University of Agriculture. Trials were arranged in four-replication randomized blocks with plot size of 16.8 m^2. Row width was 0.7 m. Planted population density was 83300 plants per ha. Original seed of ten maize hybrids (Factor B) in 2008, of eleven maize hybrids in 2009, and of fifteen maize hybrids in 2010 and 2011 (Factor A) with different maturity ratings defined by FAO number were used: Tango* (standard, FAO 210), Target[a] (FAO 180), Estelle[a] (FAO 200), Salgado* (FAO 200), Silas* (FAO 210), Turini[a] (FAO 220), Marco[b] (FAO 220), Progress[b] (FAO 220), Ceklad* (FAO 235), Ronaldinio** (FAO 240), Bombastic[b] (FAO 240), Celio* (FAO 250), KX A8151** (FAO 250), Cemet* (FAO 260), Fernandez** (FAO 260), Paroli[b] (FAO 260), Celido* (FAO 270), and Cefran** (FAO 340). The seven hybrids marked with asterisk were used in all trial years, four hybrids marked with two asterisks – in three (2009-2011) years, but others – only in one year – 2008 ([a]) or in last two years: 2010 and 2011 ([b]). Soil at the site was strongly altered by cultivation: sand loam with pH KCl – 6.7, available for plants content of P – 112 mg kg^{-1}, K – 99 mg kg^{-1}, and humus content – 19 g kg^{-1} in 2008, sand loam with pH KCl – 6.4, available for plants content of P – 129 mg kg^{-1}, K – 143 mg kg^{-1}, and humus content – 21 g kg^{-1} in 2009; and sod-gleyic sand loam with pH KCl – 7.2, available for plants content of P – 232 mg kg^{-1}; K – 190 mg kg^{-1}, and humus content – 26 g kg^{-1} in 2010 and 2011. Traditional soil tillage was used: mould-board ploughing in previous fall, cultivation and rototilling before sowing in spring. The following fertilizers were given: 148 kg ha^{-1} N (18+70+60), 34 kg ha^{-1} P, 75 kg ha^{-1} K. Maize was sown on May 6. Planting was carried out by a hand-handled planter at a 3-4 cm depth. Weeds were controlled by spraying herbicides: Arrat d.g. (tritosulfuron, 250 g kg^{-1}; dicamba, 500 g kg^{-1}) 200 g ha^{-1} and Titus 25 d.g. (rimsulfuron, 250 g kg^{-1}) 30-50 g ha^{-1} together with surfactant in 2008 and 2009, and Maisters OD 61 s.c. (foramsulfuron, 30 g L-^{1}, + jodosulfuron-methyl-sodium, 1 g L^{-1}) 1.5 L ha^{-1} + Estet 600 e.c. (2.4 – D, 600 g L^{-1}) 0.5 L ha^{-1} in 2010 and 2011 were applied when maize reached 3-6 leaves stage. In addition, Lontrel s.c. (clopiralid, 300 g L^{-1}) 0.4 L ha^{-1} together with Estete e.c. 0.5 L ha^{-1}were applied in 2009 for control of *Tussilago farfara* and *Artemisia vulgaris*. Mechanical weeding was used for the remained weeds in later maize development stages (in July of all years). Harvesting was done at three different times beginning on 5 September in 2008 and 2011, on 4 September in 2009, and on 3 September in 2010 at fourteen-day intervals. The yield was accounted from 0.7 m^2 at first and second harvest times, and from 8.4 m^2 at last harvest time. Samples were taken for every hybrid from every replication.

Composition of fresh maize yield was analyzed for all hybrids using standard methods: dry matter (DM) (samples were dried up to constant weight at 105°C) and organic dry matter (ODM) (calculated from DM and ash content) content. Results were statistically processed using methods of correlation and regression analysis.

Daily maximum and minimum temperatures were recorded by an automatic weather station located near the field experiment.

Sum of precipitation during the same period (May-September) was 230 mm in 2008, 327 mm in 2009, 454 mm in 2010, and 420 mm in 2011.

June and September of 2008 were cool, and the season in general was dry if compared with long-term average data; sum of active temperature was 1943 °C. Start of the season (May, June) in 2009 was too cold (Table 1) and unsuitable for the development of maize, but average day and night temperature in September was warmer if compared with long-term average data, active temperature sum per season was 2037 °C. The vegetation period in 2010 and 2011 was very suitable for development of maize. The trial years (2010-2011) were warmer than the long-term average. For characterizing conditions for maize growing in specific year, growing degree days (GDD) were calculated. To calculate daily GDD accumulation, the average temperatures for that day were taken (lowest plus highest, divided by 2) and subtracted the base temperature, which for maize is 10 °C. If the lowest temperature for a day is above 10 °C and the highest is 32 °C or lower, then this calculation can be done using actual temperature. If the lowest temperature is less than 10 °C, then 10 °C was used as the low temperature in the equation. If the highest temperature is above 32 °C, then 32 °C was used as the high temperature in the equation (Hoeft et al., 2000).

In 2010, accumulated GDD between planting and last harvest date were greater (931) if compared to 2011 (893), 2009 (761), and 2008 (735) respectively.

Table 1

The average day and night temperature and precipitation during maize growing season in 2008-2011 and in comparison with long-term average

Month	Long-term average temperature	Temperature, ºC				Long-term average precipitation	Precipitation, mm			
		2008	2009	2010	2011		2008	2009	2010	2011
May	11.2	11.3	11.0	11.9	11.3	43	24.2	18.0	72.6	47.6
June	15.1	14.6	13.7	14.6	16.8	51	44.2	95.0	37.8	40.0
July	16.6	17.1	17.1	20.8	18.8	75	56.8	136.0	131.8	149.8
August	16.0	16.4	15.8	18.2	16.1	75	90.2	38.8	133.4	150.6
September	11.5	10.6	12.9	10.8	12.5	59	14.8	39.8	78	32.2

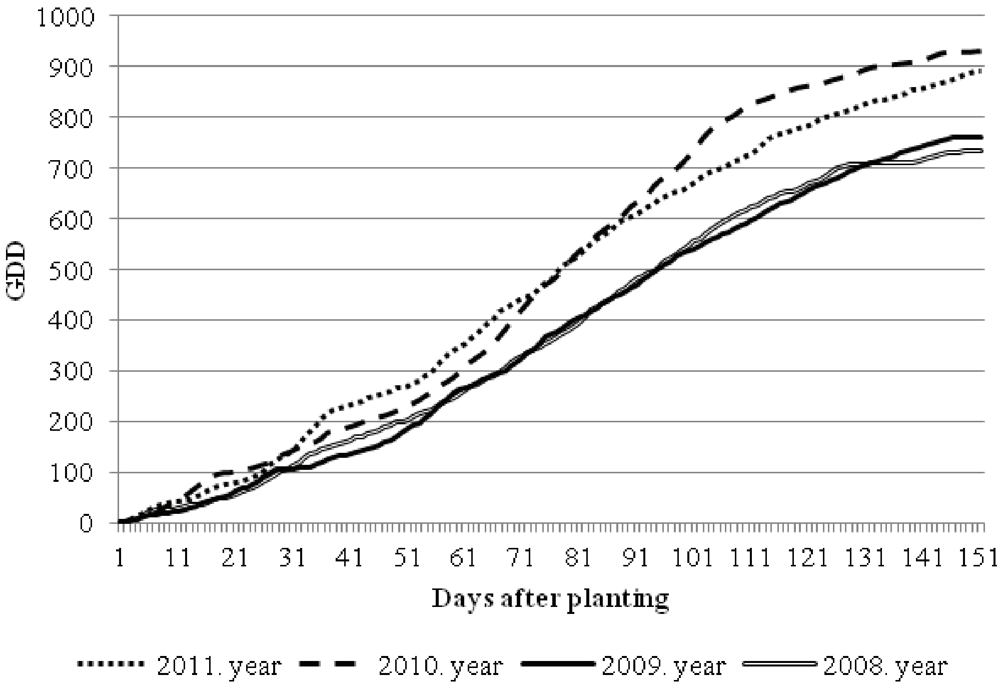

Figure 1. **GDD accumulation in the period between planting and last harvest date in all years**

Figure 1 shows that all the season of 2011 and 2010 was characterized by better warmth conditions if compared with 2009 and 2008.

Results and Discussion

In 2008, original seed of ten forage maize hybrids was used, because we were not informed about hybrids' best performance for biogas production. In that study year we tried to find out which maize hybrid produces the highest rate of organic dry matter (ODM) for biogas production. Consequently, starting with the second trial year, we included some new hybrids that are specially bread for biogas production. ODM yield substantially ($p<0.05$) depended on harvest timing in 2008. Average ODM yield increased by 2.35 t ha^{-1} from September 5 till October 3. Maize hybrid influence on ODM yield at first two harvest times (September 5 and September 19) was not substantial ($p=0.41$ and $p=39$, respectively), but maize hybrid influence at last harvest time (3 October) was substantial ($p=0.02$). Maize hybrid influence on average ODM yield also was not substantial ($p=0.148$) in 2008.

Performance of seven maize hybrids included in the trial during four years (2008-2011). Comparing results of all four trial years and of seven maize hybrids', ODM yield substantially ($p<0.05$) depended on harvest time. Average ODM yield increased from first till last harvest date. The influence of maize hybrid and vegetation period on average ODM yield was substantial ($p<0.05$). Highest average ODM yield from those seven hybrids per all years and harvest times gave hybrid Celio (13.99 t ha^{-1}). The highest average ODM yield per all harvest dates was reached in 2011 (15.48 t ha^{-1}). Range of average ODM yield of maize hybrids per all four trial years was wide – from 11.81 t ha^{-1} in 2008 to 15.48 t ha^{-1} in 2011 (Table 2). The lowest average yield of ODM yield was noted for hybrid Ceklad (12.15 t ha^{-1}). Our results showed that ODM yield in

Table 2

Organic dry matter yield of maize depending on year, hybrid and harvesting time, t ha^{-1}

Year - factor A	Harvest date	Hybrid - factor B							Average for A p<0.05
		Tango	Ceklad	Celio	Cemet	Celido	Salgado	Silas	
2008	05.sept	11.63	10.23	11.17	10.47	10.85	10.96	9.70	11.81
	09.sept	12.23	11.58	12.29	12.14	11.38	12.18	10.54	
	03.okt	11.59	11.96	12.99	14.29	13.59	13.00	13.23	
2009	04.sept	8.63	7.80	12.39	11.11	9.00	9.01	10.37	12.27
	21.sept	9.90	12.53	14.46	11.75	12.09	15.32	11.76	
	05.okt	13.51	13.37	14.87	15.18	13.03	15.72	15.85	
2010	03.sept	13.95	12.53	15.69	16.64	13.35	12.93	17.40	15.05
	17.sept	12.30	15.56	16.71	15.37	13.59	16.71	16.55	
	04.okt	12.24	13.74	15.30	16.67	16.33	15.47	16.91	
2011	05.sept	12.91	15.23	15.22	15.86	15.06	15.08	17.56	15.48
	19.sept	13.54	14.56	17.29	15.32	15.64	13.41	15.90	
	03.okt	15.22	16.50	15.87	16.69	15.21	15.74	17.40	
Average for B; p<0.05		12.30	12.15	13.99	13.73	12.58	13.48	13.59	x

Table 3

Organic dry matter yield of medium ripening maize depending on year, hybrid and harvesting time, t ha^{-1}

Year - factor A	Harvest date	Hybrid - factor B							Average for A p<0.05
		Ronaldinio	Celio	KX A8151	Cemet	Fernandez	Celido	Cefran	
2009.	04.sept	12.25	12.39	11.80	11.11	12.02	9.00	9.43	13.51
	21.sept	15.55	14.46	13.56	11.75	15.79	12.09	12.66	
	05.okt	16.09	14.87	17.93	15.18	17.44	13.03	15.22	
2010.	03.sept	15.88	15.69	18.34	16.64	20.57	13.35	16.75	17.21
	17.sept	18.16	16.71	19.24	15.37	18.59	13.59	16.48	
	04.okt	20.05	15.30	19.00	16.67	21.79	16.33	16.83	
2011.	05.sept	16.87	15.22	15,50	15.86	18.76	15.06	12.58	16.26
	19.sept	17.32	17.29	16.41	15.32	20.68	15.64	14.72	
	03.okt	16.67	15.87	15.73	16.69	16.46	15.21	17.66	
Average for B p<0.05		16.54	15.31	16.39	14.95	18.01	13.70	14.70	×

2008 and 2009 at all harvest dates was lower than that at all harvest dates in 2010 and 2011.

Performance of maize hybrids included in the trial during three years (2009-2011). Also comparing three – trial – year results of the group of four early ripening (200 – 239) maize hybrids and of the group of seven medium ripening maize hybrids (240 – 340), ODM yield substantially ($p<0.05$) depended on harvest date. In both maturity groups, ODM yield substantially ($p<0.05$) depended on conditions of vegetation period, and hybrid influence also was substantial ($p<0.05$). Average ODM yield per all harvest times and three (2009-2011) years of early ripening (FAO 200-239) maize hybrids was 13.98 t ha^{-1}, but of medium ripening maize hybrids (FAO 240 – 340) at the same harvest dates per three years – 15.66 t ha^{-1}. Among the maize hybrids of maturity class FAO 200-239, the hybrid Silas gave the highest ODM yield per hectare (15.52 t ha^{-1}). Among the hybrids of maturity class FAO 240-340, the highest ODM yield was achieved by the hybrid Fernandez (18.01 t ha^{-1}). The highest average yield in all harvest dates among early ripening hybrids was in 2011 (15.25 t ha^{-1}), and among medium ripening hybrids in 2010 (17.21 t ha^{-1}) (Table 3). A. Lemmer et al. (2003) found that the maize hybrids showed a clear dependence of dry matter yield per unit area on the time of harvest and maturity group.

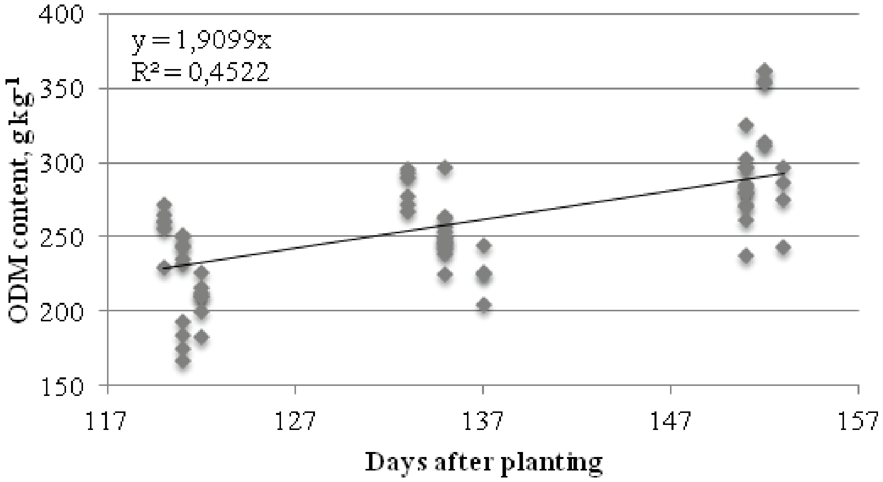

Figure 2. **ODM content of early ripening maize per all years depending on harvest time after sowing, p<0.05.**

Performance of maize hybrids included in the trial during two years (2010-2011). Suitable air temperature during the late three months of the growing season (July–September) caused good climatic conditions for biomass production in both last trial years (2010 and 2011). The greatest gain of ODM yield per hectare when harvesting later was found for hybrids included into the medium ripening group (FAO 240-340) in two trial years (2010-2011). Among the maize hybrids from maturity class FAO 200-239, the hybrid Silas gave the greatest ODM yield per hectare (16.95 t ha^{-1}). Among the hybrids of maturity class FAO 240-340, the highest ODM yield was achieved by the hybrid Fernandez (19.47 t ha^{-1}). There was an insignificant ($p>0.05$) year influence on ODM yield of early ripening maize hybrids, but hybrid and harvest date substantially ($p<0.05$) influenced ODM yield. A strong effect of meteorological conditions and hybrid on ODM yield was noted ($p<0.05$) for medium ripening maize hybrids, but influence of harvesting time was insignificant ($p>0.05$).

T. Amon et al. (2004) found that for late ripening maize hybrids the optimum methane yield per hectare is achieved if maize is harvested at the stage of dry matter content higher than 430 g kg^{-1} (43%). Methane yield from late ripening hybrids reached a maximum at full ripeness. Possibility in our conditions to reach so late developmental stage and so high DM content in yield is doubtful even using early maturity hybrids. In addition, hybrids which are considered medium ripening, in conditions of middle Europe are only early ripening.

There was a significant correlation between harvest time and ODM content of early ripening (FAO 180-239) maize hybrids ($r = 0.79 > r_{0.05} = 0.25$) (Figure 2) and also of medium ripening (FAO 240-340) hybrids ($r = 0.68 > r_{0.05} = 0.21$). Range of ODM content of all maize hybrids per all three harvest dates and all years was wide (from 158.73 g kg^{-1} (Celido at first harvest date in 2009) to 362.1 g kg^{-1} (Salgado at last harvest time in 2010)).

When maize was harvested with a high content of dry matter, the C:N ratio was outside the optimum range with regard to producing a maximum specific methane yield. Co-digestion of substrates with a narrower C:N ratio could help to overcome this disadvantage (Oslaj et al., 2010).

Conclusions

Four year period allowed to evaluate maize performance in different meteorological conditions – two years (2010-2011) were suitable even for growing medium ripening (FAO 240-340) hybrids, but in two years only earlier maturing (FAO 180-239) hybrids provided yield with more acceptable ODM content at later harvest dates. Our results showed that ODM yield in 2008 and 2009 at all harvest dates was lower than that at all harvest dates in 2010 and 2011. Warmth conditions of season were of great importance. But even in complicated growing conditions of 2009, some medium ripening hybrids (like Ronaldinio (FAO 240), Fernandez (FAO 260), and KXA 8151 (FAO 250)) showed good results.

Maize hybrid, vegetation period and hybrid influence on average ODM yield was substantial ($p<0.05$). An exception was noted if only results of last trial years (2010 and 2011) were compared: then harvest time influence was insignificant ($p>0.05$) for medium ripening maize hybrids and vegetation period influence was insignificant ($p>0.05$) on ODM yield of early ripening maize hybrids. The highest average ODM yield in all years was reached when maize was harvested at the last harvest time. But, according to the results of current investigation, it was not possible to conclude unambiguously that the last harvest date was always the best one: it depended on season and used hybrid. There was a significant correlation between the length of the growing season (days from sowing till harvesting) and the ODM content at harvest.

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THE ESTIMATION OF ENERGY EFFICIENCY OF CROP ROTATION IN LONG –TERM TRIALS

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Abstract
The aim of the work is to establish the energy-efficiency of long-term experimental field "Sidrabini" at the Research Institute of Agriculture of Latvia University of Agriculture. The crop rotation of winter triticale, spring wheat, spring barley, spring oilseed rape and potato was tested on the influence of increasing fertilizer rates during 1994 – 2008. Four fertilizer doses were tested: NPK 0-0-0, NPK 45-30-45, NPK 90-60-90 and NPK 135-90-135. Energy-efficiency was calculated using methodology developed by the Moscow Timirjazev Russian State Agrarian University (Методология и методика…, 2007).
Research results show that the spring rape used 32 GJ ha^{-1}, cereals consumed 30 -35 GJ ha^{-1} and potatoes - 66.5 GJ ha^{-1} of energy, but the yields were obtained: 42 GJ ha^{-1} from oilseed rape, 46–63 GJ ha^{-1} by cereals and 119 GJ ha^{-1} from potatoes. The energy efficiency ratio was 1.3 for spring rape, 1.5–1.8 for cereals and potatoes - 1.8.
The highest energy efficiency was obtained by growing triticale and potato, but lowest - growing spring oilseed rape. Growing a crop without a fertilizer, energy expenditure was equal to the energy accumulated in the yield (energy efficiency ratio 1.0), but using fertilizers, regardless of the fertilizer rate, the energy efficiency ratio was 1.6.
Key words: energy efficiency, mineral fertilizers, crop rotation.

Introduction

Every day mass media inform that fossil energy raw materials slowly become exhausted on Earth. Energy saving is urgent today in completely different way. Therefore, ever more attention must be drawn to renewable natural resources, which can be used for energy production.

A total amount of energy resources used for growing energetic cultivated plants (fuel, mineral fertilizers, etc.) often exceeds an amount of energy obtained from the product produced. Energy invested in production comes mostly from non-renewable natural resources, which, with their exhaustion, become more and more expensive. Energy utilization efficiency improvement is significant. Therefore, on 28 January 2010 Latvia adopted the law on energy end-consumption efficiency, which also concerns agriculture (Energy End-consumption Efficiency Law, 2010). A lot of attention in plant cultivation industry is currently paid to growing of energetic plants (*Renewable energy resources…*, 2008; Adamovičs et. al., 2009), however, energy utilization in plant cultivation technologies is not sufficiently valued and energy-efficiency thereof is not sufficiently analysed.

Growing conditions, especially use of mineral fertilizers, significantly affect chemical composition of products. Content of proteins and fats in those products changes, which alters energy content in yield. This must be taken into account in evaluation of cultivated plant growing technologies or varieties. Knowing the total amount of energy consumed for growing of cultivated plants and energy content in products enables evaluation of energy-efficiency of growing cultivated plants.

Energy-efficiency evaluation allows comparing different agricultural production technologies in respect of energy-resources consumption, establishing structure of energy flows in agrophytocenosis and identifying main reserve energy saving technologies in agriculture.

The aim of the research was to establish the energy-efficiency of long-term experimental field "Sidrabini" during 1994-2008.

Materials and Methods

In 1981, the agency of Latvia University of Agriculture, Research Institute of Agriculture, under the leadership of professor J. Štikāns arranged a long-term experimental field in gleyic sod-podzolic soil (PGg) with sandy loam granulometric composition. Main field crops – rye, triticale, spring barley, spring wheat, oats, potatoes, spring oilseed rape – as well as perennial grasses in I and II years of use were cultivated at long-term experimental field "Sidrabini". Four variants with different content levels of soil organic substances, soil reaction, plant nutrients – nitrogen, phosphorus and potassium created at the station. The test was arranged according to a two factors scheme, which allows for studying the effect of four lime doses (0; 2.85; 5.7 and 11.4 tons per hectare) on yields of cultivated plants; these variants

$N_0P_0K_0$	F_0L_0 0 t ha^{-1} $CaCO_3$	O	$N_{90}P_{60}K_{90}$	F_2L_0 0 t ha^{-1} $CaCO_3$
$N_0P_0K_0$	F_0L_3 11.4 t ha^{-1} $CaCO_3$	O	$N_{90}P_{60}K_{90}$	F_2L_1 2.85 ha^{-1} $CaCO_3$
$N_0P_0K_0$	F_0L_2 5.7 t ha^{-1} $CaCO_3$	O	$N_{90}P_{60}K_{90}$	F_2L_2 5.7 t ha^{-1} $CaCO_3$
$N_0P_0K_0$	F_0L_1 2.85 ha^{-1} $CaCO_3$	O	$N_{90}P_{60}K_{90}$	F_2L_3 11.4 t ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_0 0 t ha^{-1} $CaCO_3$	O	$N_{135}P_{90}K_{135}$	F_3L_0 0 t ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_3 11.4 t ha^{-1} $CaCO_3$	O	$N_{135}P_{90}K_{135}$	F_3L_1 2.85 ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_2 5.7 t ha^{-1} $CaCO_3$	O	$N_{135}P_{90}K_{135}$	F_3L_2 5.7 t ha^{-1} $CaCO_3$
$N_{45}P_{30}K_{45}$	F_1L_1 2.85 ha^{-1} $CaCO_3$	O	$N_{135}P_{90}K_{135}$	F_3L_3 11.4 t ha^{-1} $CaCO_3$

Figure 1. **The scheme of long-term experimental field "Sidrabini"**

were designated in the scheme as L_0; L_1; L_2 and L_3, and the effect of four norms of mineral fertilizers (NPK 0-0-0; NPK 45-30-45; NPK 90-60-90; NPK 135-90-135), designated respectively F_0; F_1; F_2 and F_3, on yields and quality of cultivated plants (Figure 1).

The study analyzes energy in respect of collected and consumed amount of energy of cultivated plants in the first rotation of plants for 7 years from 1994 to 2000 – and in the second rotation of plants for 7 years from 2002 to 2008. Calculations were based on the methodology of Russian State Agricultural University named after K. Timiryazev. Energy amount collected from the yield of cultivated plants was calculated using average factors of energy value equivalents (MJ per kg). Energy consumption for growing a specific variety of cultivated plants was determined by summing energy consumptions of individual technological operations according to the following formula:

$$E_c = \sum_{i=1}^{N} \left(Z_i^G \times K_i^G + Z_i^T \times K_i^T + Z_i^E \times K_i^E \right) + \left(t_i^D \times K_i^D + t_i^M \times K_i^M + m_i^D \times K_m \right) + E_p \tag{1}$$

where:

- E_c – total costs of energy for crop production (MJ ha^{-1});
- Z_i^G – fuel consumption (kg);
- Z_i^T – labour consumption (working hours);
- Z_i^E – power consumption (kWh);
- K_i^G – the energetic equivalent of fuel consumption (MJ kg^{-1});
- K_i^T – the energetic equivalent of labour consumption (MJ working h^{-1});
- K_i^E – the energetic equivalent of power consumption (MJ kWh^{-1});
- t_i^D – tractor-engine working hours (h);
- t_i^M – agricultural machinery working hours (h);
- K_i^D – depreciation of the energetic equivalent of one tractor-engine-time unit (MJ h^{-1});
- K_i^M – depreciation of the energetic equivalent of one agricultural machinery-time unit (MJ h^{-1});
- m_i^D – mass of material resources (kg ,m^3);
- K_m – mass equivalent of material resources (MJ kg^{-1}, MJ m^{-3});
- E_p – energy costs for equipment repair and servicing (MJ ha^{-1}).

Energy value ($E_{u)}$ collected from yield was determined according to the following formula:

$$E_u = U \times K_u \tag{2}$$

where:

- U – yield of crops (kg ha^{-1});
- K_u – energetic equivalent of yield (MJ kg^{-1}).

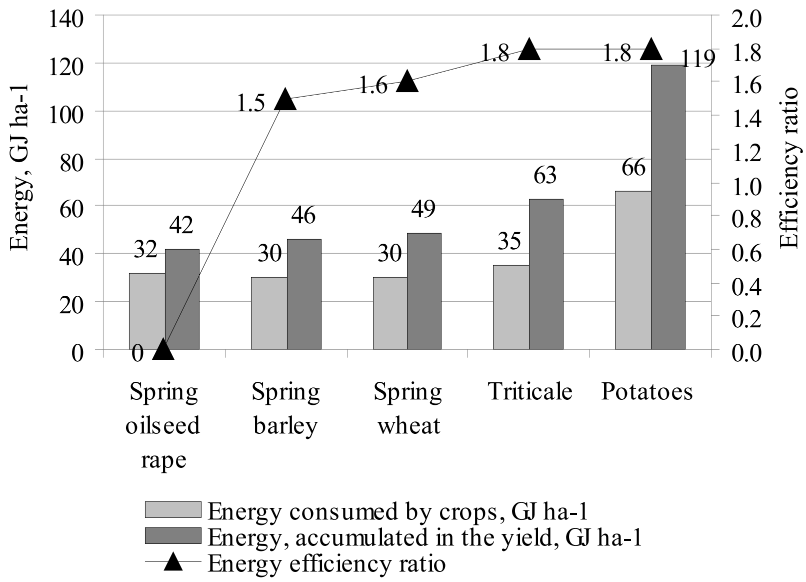

Figure 2. **Energy efficiency of crops**

Table 2

Energy efficiency of crops depending on mineral fertilizers norms

Crops	Norms of mineral fertilizers			
	NPK 0-0-0	NPK 45-30 45	NPK 90-60-90	NPK 135-90-135
Spring oilseed rape	0.9	1.7	1.8	1.6
Triticale	0.9	1.7	1.3	1.6
Spring wheat	1.3	1.8	1.6	1.6
Spring barley	1.3	1.7	1.8	1.5
Potatoes	0.7	1.2	1.5	1.7
Average	1.0	1.6	1.6	1.6

The factor of energy efficiency of agricultural cultivated plants, which was determined as a relation between energy capacity of obtained yield (energy collected with yield) and energy consumption for its obtaining (energy consumed for growing of cultivated plant), was used as a criterion of crop rotation energy efficiency:

$$K = \frac{E_u}{E_c} \qquad (3)$$

where:

- K – energy efficiency
- E_u – energy accumulated in the yield (MJ ha^{-1});
- E_c – energy consumed by a crop (MJ ha^{-1}).

Results and Discussion

In making tests, first, energy consumed for obtaining the yield of field crops, grown in field tests, was established. Energy consumption was established by summing individual energy consumptions of technological operations and materials used in these field tests. Figure 2 summarizes results obtained in the tests regarding the study variant, where the norm of mineral fertilizers was NPK 90-60-90.

Energy efficiency ratio rating:

- K=0 – energy expenditure is equal to the energy accumulated in the yield;
- K>1 – the energy accumulated in the yield is higher than energy expenditure;
- K<1 – production consumes more energy than its generation

The least energy was consumed for obtaining of yield of grains of spring wheat and barley: 30 GJ per hectare, slightly more energy was necessary for obtaining of yield of spring rape and winter triticale: 32 GJ per hectare and 35 GJ per hectare, respectively. Approximately twice as much energy as for grain plants and for obtaining of yield of spring rape was consumed for obtaining of yield of potatoes: 66 GJ per hectare. However, growing potatoes, the highest amount of energy was obtained from the yield of nodules: 119 GJ per hectare. The next highest amount of energy was obtained growing winter triticale: 63 GJ per hectare. 49 GJ per hectare was obtained from spring wheat seeds, 46 GJ per hectare – from barley, and the least, just 42 GJ per hectare – from spring oilseed rapeseeds. Therefore, the highest energy efficiency factor was in yields of potatoes and triticale: 1.8, it was slightly lower for spring wheat and barley: 1.6 and 1.5, respectively, and the lowest – for spring rape: just 1.3. Field crop cultivation efficiencies, using different norms of mineral fertilizers, are shown in Table 2.

Test results show that the average energy efficiency factor without mineral fertilizers (NPK 0-0-0) was the lowest: 1.0. Using mineral fertilizers, spring rape and spring wheat had the highest energy efficiency factor in variant with the lowest norm of mineral fertilizers (NPK 45-30-45): 1.7 and 1.8, respectively, and the highest for winter triticale and potatoes it was, using the average norm of mineral fertilizers: 1.8, in its turn, for barley the highest energy efficiency factor was when using the highest norm of mineral fertilizers: 1.7. The average energy efficiency factor at the stage of crop rotation for all field crops grown in the tests with all three norms of mineral fertilizers was similar: 1.6. The study results show that the highest energy efficiency was obtained in growing winter triticale and potatoes, using the norm of mineral fertilizers NPK 90-60-90, and, growing spring wheat, the best energy efficiency factor was in variant with the lowest norm of mineral fertilizers NPK 45-30-45. Growing field crops without mineral fertilizers, yield was very low, and energy, used for growing, was equal to the energy value of obtained products.

Conclusions

The research results show that the spring rape used 32 GJ ha^{-1}, cereals consumed 30 -35 GJ ha^{-1} and potatoes - 66.5 GJ ha^{-1} of energy, but the yields were obtained: 42 GJ ha^{-1} from oilseed rape, 46–63 GJ ha^{-1} by cereals and 119 GJ ha^{-1} from potatoes. The energy efficiency ratio was 1.3 for spring rape, 1.5–1.8 for cereals and potatoes - 1.8.

The highest energy efficiency was obtained by growing triticale and potato, but lowest - growing spring oilseed rape.

Growing a crop without a fertilizer, energy expenditure was equal to the energy accumulated in the yield (energy efficiency ratio 1.0), but using fertilizers, regardless of the fertilizer rate, the energy efficiency ratio was 1.6.

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REED CANARY GRASS *(PHALARIS ARUNDINACEA* L.*)* IN NATURAL BIOCENOSIS OF LATVIA, RESEARCH EXPERIMENTS AND PRODUCTION FIELDS

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Abstract

In recent years, perennial grasses have not been considered only as a forage crop but focus has shifted to their usage as an energy crop. Special interest has been caused by reed canary grass, which is widely spread in natural biocenosis. The scientific expeditions have been organized and all regions of Latvia have been explored to gather material and information about biodiversity of perennial species of wild grasses. Several natural populations of reed canary grass (*Phalaris arundinacea* L.) were collected under different soil and climate conditions. The accessions were of different quality in many respects depending on collection site. Samples taken from the marshy meadows on lakeshore of the Lake Lubana were coming into flowers unevenly over a longer period of time and formed a little number of culms, whereas samples collected on the banks of the River Daugava were earlier and formed considerably more culms and were coming into flowers evenly over a shorter period of time.

Breeding on reed canary grass in Latvia has not been done previously. Attention to the wild populations of RCG usually has been focused on their feeding value. Though, these populations have a good potential for selection of a new varieties intended for varied purposes. The field trials with ten wild accessions of RCG were established, and winter hardiness, growth intensity and various phenological observations were evaluated. After a comprehensive evaluation of the wild populations by important economic and morphologic characteristics, some valuable samples were found. The population 'Brigena' proved such valuable characteristics as good winter hardiness, high dry matter yields, and intensive development of productive culms. In recent years, consumption of reed canary grass as energy feedstock has increased rapidly in Latvia. It is grown by farmers in all regions and the total planted area has exceeded 800 ha. Mostly are grown varieties 'Marathon' (USA) and 'Bamse' (Sweden). DM yields obtained by farmers in Latvia on average are 6 - 9 t ha^{-1}. Further research has to be continued.
Key words: energy crop, reed canary grass, varieties, wild populations.

Introduction

Latvia is situated on the coast of the Baltic Sea, in the temperate climate zone, accordingly perennial grasses are the most cultivated plants on the farmlands, as well as they are widely spread in natural meadows, pastures, and other habitats. Areas covered by natural meadows and pastures are 9.5% of the total area of Latvia territory (Boruks, 2004).

Perennial grasses have many characteristics desirable for a good field energy crop: high yield potential, high content of lignin and cellulose. Planting perennial grasses might have positive environmental impact on biodiversity; areas of arable land are reduced ensuring that soil erosion is lowered and carbon content increased, as well cultural landscapes are managed. Previous researches and tests on usage of perennial grasses for biomass production in the Nordic countries has proved that a perennial rhizomatous grass, reed canary grass, is the most productive grass in terms of stable biomass yield in the northern latitudes (Landström and Olsson, 1997; Lewandowski *et.al*., 2003; Saijonkari- Pahkala, 2001). Perennial biomass crops require fewer inputs, produce more energy, and reduce greenhouse gas emissions more than annual cropping systems (Adler *et.al*., 2007).

Numerous studies on reed canary grass usage for different purposes have been conducted in several European countries, in Scandinavia, and in the USA, while in Latvia there have been carried out only few researches on this issue. In recent years, focus has been shifted to reed canary grass as an industrial crop for bioenergy production also in Latvia, where RCG is widely distributed in natural biocenosis. Plant breeding work regarding this specie has not been done previously in Latvia. For this reason, scientific expeditions with the aim to gather basic material and information about biodiversity of perennial species of wild grasses had been organized in all regions of Latvia (Rancane *et al*., 2006). Reed canary grass in wild occurs in meadows on lakeshores, on the river banks subject to overflowing, as well as on other fertile wetlands. Wide areas covered by RCG grass stands were found on the banks of the Lake Lubana and the River Aiviekste, in the meadows that are overflowed by the waters of the River Pededze in springs, on the left bank of the River Daugava, in the areas between the River Suseja and the Lake Brigena, in the areas surrounding the Lake Papes in Kurzeme region, as well as in other places.

There are many different forms of the RCG growing in the wild: from types with narrower and darker blades to plants having many culms and panicles of spikelets producing more seeds. Reed canary grass has a wide geographic adaptation; genetic variation is present that can be used to select genotypes for specific environments (Cristian *et al*., 1997). For the breeding purposes, there are available samples useful as a forage crop, and the samples with qualities more appropriate for energy generation. New high yielding varieties has to be developed with a quality different from the forage-type varieties. High stem/ leaf ratio, low content of ash and elements like silica, potassium and chlorine are important breeding goals (Lindvall, 1996).

Several natural populations of reed canary grass have been collected in variegated soil and climate conditions in order to test and evaluate the wild material in field trials at the Latvia University of Agriculture Research Institute of Agriculture.

Materials and methods

The wild accessions have been collected mostly from natural meadows, lakeshores, and river banks. Coordinates of collecting places were the following: latitude 56°16-57'N, longitude 26°10-51'E; elevations ranged from 2 to 132 m above sea level. The most proper time for collection of seeds from perennial grasses in Latvia is from the middle of July till the middle of September.

To evaluate 10 wild accessions of reed canary grass, field trails were established at the Research Institute of Agriculture in Skriveri during 2005-2008. The Institute of Agriculture's experimental fields' characteristic conditions are as following: precipitation of 700-800 mm per year, a vegetation period of 160-180 days, and average active temperatures ranging from 1900 to 2000°C. Under the mentioned conditions, two high perennial forage crop yields are commonly obtained; the third harvested yield usually is poor.

The trials for testing of reed canary grass samples were arranged at the field where topsoil was 25 - 27 cm, organic content 1.9 %, pH_{KCl} 5.6, K_2O 78 mg kg^{-1}, P_2O_5 168 mg kg^{-1}. The experiment was comprised of randomized complete block design with 3 replications; the size of plot was 1.2 m^2. Seeds were sowed by hand in the middle of May. Local populations have been named by their area of origin.

In the sowing year, tendency to develop generative browses and diseases resistance before wintering was estimated. In the following spring, the trial plots received fertilizers at the following rates: N = 60 kg ha^{-1}, P_2O_5 = 30 kg ha^{-1}, and K_2O = 70 kg ha^{-1}. In the 1st year of use, winter damages, regrowth intensity in the spring and after cutting, and various phenological observations were evaluated on the 9-point scale (1 - indicates the signs of a weaker expression, 9 - the highest).

The mathematical processing was done by a computer program Microsoft Excel subprogram for analysis of data (Berzins, 2002).

Results and discussion

During study years, from 2005 to 2008, climatic conditions over the vegetation periods and the winter periods in Latvia were different. There were both dry and hot summers, and cool and rainy ones, in the winter time there were periods of black frost. This allowed to

Table 1

Average evaluations of RCG (*Phalaris arundinacea* L.) wild-type populations (2005-2008)

Accession	Winter damages (1-without damages; 9-perished)	Regrowth at the spring (1- slow; 9- rapid)	Heading date	Inflorescences emergence intensity (1-some panicles; 9-uniform)	Plant height at flowering, cm	Total culm number (1-few; 9- very much)	Length of longest culm (1-short; 9- very long)	Susceptiblity to diseases (1-healthy; 9-highly damaged)
Lub K	2	3	18.06	6	135	4	5	2
Osupe	3	2	20.06	8	119	4	4	1
Zvid	2	3	18.06	7	148	5	6	1
Meir K	3	4	18.06	6	117	4	4	2
Krust k	3	5	10.06	6	158	3	7	1
Brigena	2	8	07.06	8	160	7	7	1
Varkava	4	3	18.06	5	120	3	4	3
Suse	5	7	08.06	3	131	5	5	3
Eglaine	3	6	10.06	4	152	5	6	3
Pape	4	8	07.06	4	167	6	8	2
LSD 0.05	0.6	2.0		2.0	15.7	0.5	1.6	1.6

Source: made by the authors

Table 2

DM (t ha^{-1}) yields of reed canary grass varieties

Variety	Harvesting year		On average 2009-2010	% to Control
	2009	2010		
Brigena	9.13	9.41	9.27	100
Marathon	8.06	8.86	8.46	88
Palaton	8.94	9.67	9.31	101
LSD 0.05	0.80	.45	.52	7.7

Source: made by the authors

Table 3

Chemical composition of reed canary grass varieties

Cultivar	1st cut					2nd cut				
	Crude protein, %	P, %	K, %	Ash, %	Digestible protein, %	Crude protein, %	P, %	K, %	Ash, %	Digestible protein, %
Brigena	11.85	0.30	2.29	6.65	45.4	12.07	0.28	1.77	5.72	37.8
Palaton	11.56	0.28	2.05	5.97	44.5	11.94	0.22	1.36	5.01	41.5

Source: made by the authors

multi-examine the wild samples and select the most valuable types for future breeding work. The collected wild-type reed canary grasses were different from each collection sites in many respects. Accessions collected from the marshy meadows near the Lake Lubana are serotinous, they are coming into flowers over a longer period and developing few culms. These types can be harvested over a longer period of time; the process of lignifications is slow, and they are more suitable as a forage grass crop.

Samples collected on the banks of the River Daugava, at the Lake Brigena and the Lake Papes develop more culms, and come into flowers evenly over a shorter period of time. The mentioned qualities offer high potential for use in bioenergy generation.

Assessment results indicated that wild samples, collected from different geographical locations in Latvia, provided higher winter hardiness results. The highest degree of winter-resistance during the 3-years period was showed by such local populations as ‘Lub K’, ‘Zvid’, and ‘Brigena’, they were evaluated with 2 points, suggesting that grass swards of above mentioned accessions had almost no observable damage thanks to their winter-resistance. Results regarding key features of 10 local RCG samples obtained from the collection nursery are summarized in Table 1.

In general, reed canary grass is very winter-hardy, and the genotypes did not have a period of dormancy, whereas dormancy is a normal characteristic of reed canary grass growth in Scandinavia (Olsson, 2004).

There were observed great differences among tested samples in regrowth intensity both in spring, and after cutting, assessments ranged from 2 to 8 points. Varied evaluation of the growth intensity allowed us to select the best samples providing a rapid regrowth in spring and after cutting. There were selected populations, which were evaluated with 7 - 8 points, ‘Brigena’, ‘Pape’, and ‘Suse’, while regrowth intensity of populations ‘Osupe’, ‘Zvid’, ‘Varkava’, and ‘Lub K’ turned out to be slow, and they were evaluated only with 2- 3 points.

Some wild populations distinguished among others with a great number of culms and the tallest culms at the flowering - over 160 cm. These quantitative characters are important for energy grass crops, including reed canary grass. Culms of the tested accessions were 117 - 167 cm tall and some differences were very significant. Taller and hence potentially most productive were the accessions: ‘Pape’, ‘Brigena’, and ‘Krust k’ (7-8 points). At the same time, shorter occurred the samples: ‘Varkava’, ‘Meir K’ and ‘Osupe’, with the length of culms not exceeding 120 cm, therefore they were evaluated with only 4 points.

Intensity of inflorescence emergence among the studied samples varied considerably within 3-8 points. ‘Osupe’, ‘Brigena’ and ‘Zvid’ flourished fast and simultaneously, while populations ‘Suse’, ‘Eglaine’ and ‘Pape’ formed only some panicles and were evaluated with 3-4 points. Since production of reed canary grass seeds is complicated and expensive, the aforementioned feature is essential.

Heading started at the beginning of June. Varieties 'Pape', 'Brigena' and 'Suse' came into flowers fast and simultaneously, while the serotonous varieties came into flowers 10 days later.

Data analysis shows that inflorescences emergence intensity have negative correlation with length of culm (-0.75), but positive correlation appears between regrowth intensity and leaf colour (0.78), and regrowth intensity and length of culm (0.77).

Reed canary grass populations collected in the natural environment proved to be resistant to a number of grass-specific diseases, including leaf mottling (*Drechslera dictyoides*) and various rust (*Puccinia*) species. The most of plants were healthy, with no observable defects.

After the comprehensive evaluation of the wild accessions by significant economic and morphological characteristics, some favourable samples were found and, as a result of further breeding work and purposeful selection, preferable variety 'Brigena' was developed.

All around the world there are well known such RCG forage-type varieties as 'Venture', 'Palaton', 'Marathon', 'Pedja', 'Lara', an industrial variety 'Bamse', recently developed in Sweden, having a DM yield about 20 % higher than forage-type varieties. Variety 'Brigena' was compared with American origin varieties 'Marathon' un 'Palaton' available in Latvia. The new bred variety proved to be multi-purpose plant, it showed such characteristics as good regrowth capacity, tall stems, good leafage, dense stands, and good dry matter yields, exceeding 9 t ha^{-1} (Table 2).

An ideal plant for energy generation has high fiber content and low content of ash, silica, potassium and chorine (Andersson and Lindvall, 1999).

Analysis of chemical composition showed that variety 'Brigena' in comparison to variety 'Palaton' has higher protein, ash, and K content in dry matter; these are considered as significant elements that characterize a good forage crop (Table 3).

In recent years, volume of RCG grown as an energy crop has been expanding rapidly in Latvia. The total area of reed canary grass grown by farmers in all regions has exceeded 800 ha. Mostly grown varieties are 'Marathon' from USA and the industrial variety 'Bamse' from Sweden. The DM yield obtained by farmers in Latvia on average is 6- 9 t ha^{-1}.

Reed canary grass grown in Latvia is harvested in the late autumn, when plants are almost dry. After harvesting, the biomass is allowed for drying, then gathered into big round bales and transported to pelletizing facilities. The average weight of a bale is 250 kg. Variety 'Bamse' has been grown for the pellets production purposes also in the fields of the Institute of Agriculture in a total area of 20 ha. In the first year, in 2010, a very high DM yield of 7.8 t ha^{-1} was obtained (absolute DM yield 6.5 t ha^{-1}). In the next year, in 2011, the obtained DM yield was lower - 6.4 t ha^{-1} (absolute DM yield 5.0 t ha^{-1}), because of deficiency in moisture over the vegetation period of reed canary grass. Data of chemical composition analysis of biomass DM harvested in autumn were as following: ash content was 6.4 % (5.0 % in spring), the highest calorific value (Q) - 17.74 MJ kg^{-1} or 4235 kCal kg^{-1} (data obtained from the spring harvest were very similar, respectively, 17.94 MJ kg^{-1} or 4286 kCal kg^{-1}). Deformation temperature for biomass harvested in the autumn was 1130 ˚C, for the spring harvest – 1250 ˚C, that can be considered as a good result. It was recorded that concentrations of the undesired elements Cl and S were about one-half lower in the spring harvest than in the autumn harvest. With every 1 % increase in ash concentration, the heating value of the fuel decreases by 0.2 MJ $kg^{-1}{}_{DM}$ (Jenkins el.al, 1996). However, it must be taken into account that biomass harvested in the spring has a high risk to reduced DM yields, and it must be evaluated whether the harvesting in the spring is beneficial in the conditions of Latvia.

Conclusions

There is a great genetic diversity of wild-type reed canary grass in the nature of Latvia.

Combined tests of variance among the populations showed significant differences in winter hardiness, regrowth intensity, total culm number, and inflorescence emergence intensity.

Wild populations 'Brigena' and 'Pape' are characterized by a number of valuable economic and biological features.

A new variety 'Brigena' has a high potential for use in forage and energy production due to high DM yields and qualities necessary for good forage.

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BIOMASS POTENTIAL OF PLANTS GROWN FOR BIOENERGY PRODUCTION

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Abstract
In 2010 and 2011, we established the biomass potential of 14 grass species and 3 tree species grown for bioenergy purposes. The tested plants were divided into groups. In the imported plants' group, the highest dry matter yield (9.58 t ha^{-1}) was produced by *Sida hermaphrodita* when cut once. Other plants of this group were less productive: dry biomass yield of *Silphium perfoliatum* was 7.29 t ha^{-1}, of *Polygonum japonica, Polygonum sachalinensis* 8.74-5.13 t ha^{-1}, respectively. Due to the cold and snowy two winters, *Miscanthus giganteum* three-four year old stand severely thinned out and the yield declined to 7.14 t ha^{-1}, at N_{60-120} kg ha^{-1} fertilization level. Of the non-traditional plants, the highest biomass content was accumulated by *Artemisia dubia* (11.10 t ha^{-1}) and *Helianthus tuberosus* (8.56 t ha^{-1}), *Artemisia dubia* biomass was 3.3 times as high as that of *Artemisia vulgaris*. In the group of local plants, unfertilized *Galega orientalis* produced 10.98 t ha^{-1} dry biomass over 3 cuts. N_{120} kg ha^{-1} –applied *Phalaris arundinacea* produced 9.89 t ha^{-1}. Other legumes, *Medicago sativa and Onobrychis viciifolia,* in the sowing year and first year of use produced little biomass 6.16-5.21 t ha^{-1}.
Forest plants were cut in the autumn of 2010 after 3 growing seasons (2008-2010). The largest amount of dry biomass was produced by *Salix viminalis* 32.7-38.1 t ha^{-1} and *Populus nigra* 24.0-33.0 t ha^{-1}. When forest plants were grown in arable land, nitrogen fertilization had little effect on biomass yield, a biomass reduction trend was observed at N_{120} kg/ha fertilization. *Salix viminalis* had also low nitrogen and sulphur contents. *Salix viminalis* was best suited for combustion.
Key words: biomass, productivity, fertilization, bioenergy, tolerance.

Introduction

One of the renewable energy resources is plant biomass. In terms of moisture, our climate is favourable for most plants - the sums of active temperatures vary on average from 2000 to 2250°C. As a result, not only indigenous *Poacea* family's C_3 plants but also imported C_4 type plants, possessing very high energy potential, are a promising material for bioenergy production. Up till now, imported plants (*Sida hermaphrodita*, *Polygonum japonica, Polygonum sachalinensis ,Miscanthus giganteum*) have been encountered as single specimens or in groups but only as ornamental plants. There is little research done in Lithuania into the choice and cultivation of plants designed for energy needs. Willows of some local flora and introduced *Salix* L. taxa have been comprehensively researched at the Institute of Botany by D. Smaliukas. His research evidence suggests that the yield of air-dry above-ground stem biomass of the six-year-old plantations was 45-55 t ha^{-1}. Willow trees grown on light soils produced an annual biomass yield of 5.60 t ha^{-1} over the first three years of cultivation. (Smaliukas, 1996). At the Institute of Agriculture, in Dotnuva, the yield of dry biomass of perennial tall grasses amounted to 6–9 t ha^{-1} and only in favourable years it amounted to up to 12 t ha^{-1} (Kryževičienė, 2006; Jasinskas at al., 2008). Continuing the search for potential energy crops and expecting that the global climate change processes and climate warming will become conducive to warmth-loving C_4 type plants, we chose *Miscanthus* hybrid as a research object, which had been tested under field conditions in Lithuania. Research done in the USA and Europe in various climate zones, soils and regions over the last 20 years has proved *Miscanthus* to be a plant possessing one of the highest energy biomass potentials (Clifton-Brown et al., 2004; Heaton et al., 2008). The advantage of *Miscanthus* over other energy plants is undoubted in many countries of warmer climate zones; however, research evidence obtained in the cooler climate zones is rather diverse. The summarised results of tests done on 15 *Miscanthus* genotypes in Sweden, Denmark, England, Germany and Portugal suggest that the biomass yield is increasing with every year of cultivation from 2 t ha^{-1} in the first year to 9–18 t ha^{-1} in the second and third years. The green biomass of individual hybrid lines totalled from 29 to 40.9 t ha^{-1} (Clifton-Brown et al., 2001). It has also been noted that the genotypes that yielded better in cooler climate zones were less productive in warm climate zones. In the countries with a cooler climate, the spread of *Miscanthus* species is constrained by its susceptibility to contrasting, especially to low temperatures, and by the fact that the plants do not ripen seed (Lewandowski et al., 2000). In Lithuania, plants are often damaged by late frosts in spring and cooccurring soil droughts and hot weather spells. As a result, research on *Miscanthus* adaptivity in specific conditions is indispensable.

In Poland, our neighbouring country, *Miscanthus, Sida hermaphrodita* and 7 *Salix* genotypes were grown for energy purposes in alluvial humus-rich and alluvial sandy soils. Of all the tested plants, *Salix viminalis* was proved to be the most productive one. On more fertile soils its biomass yield in 2001-2004 was 10.1 t ha^{-1} DM, in different soils biomass yield varied from 7 to 13 t ha^{-1} DM (Nalborczyk 2005; Szczukowski et al.2006)

The search for and development of renewable energy sources in Lithuania as well as rational use of their resources is becoming increasingly relevant. The study was aimed to explore growth and development peculiarities of the perennial plants differing in origin, type and species and to estimate biomass yield as influenced by various nitrogen fertilization.

Materials and methods

The trials were conducted in Dotnuva (lat. 55º 24′ N, 23º 52′ E), in a reclaimed river bed territory. The soil is light, sand on sand with small stone and gravel admixture, *Eutri-Cambic Arenosols* (*ARb-eu*). The soil chosen for these experiments is less suited for other plants. It is neutral, deeper alkaline, with a humus status of 2%, with moderate total nitrogen, available phosphorus and potassium contents .The pre-crop was red clover of the third year of use. Early in spring, the clover field was ploughed; the soil was prepared for planting by a cultivator and a harrow. A plantation of energy plants was established in 2007. Four groups of energy plants were investigated: group 1- short rotation forest plants - *Salix viminalis* L., *Populus tremula x P. tremuloides* and *Populus nigra* L., group 2- imported herbaceous plants - *Miscanthus* x *gigantheus*, *Sida hermaphrodita*, *Silphium perfoliatum* L., *Polygonum sachalinensis* L., *Polygonum japonica* hybrid, group 3- non-traditional plants – *Artemisia vulgaris* L., *Artemisia dubia* Wall., *Helianthus tuberosus* L.), *Panicum virgatum* L. and group 4 - indigenous (local) plants as a control – *Dactylis glomerata* L., *Phalaris arundinacea* L., *Galega orientalis* Lam., *Medicago sativa* L. *Onobrychis viciifolia* L.

Salix viminalis were planted in beds with inter-row distances of 0.75 m and 1.5 between double beds. The distances between plants in rows were 0.5 m. A total of 16 000 plants were planted per hectare. *Populus* of both species was planted at a density of 1 plant per square meter, 10 000 plants per hectare. Imported plants *Polygonum* and *Silphium* were planted at a density of 1 plant per square meter, 10000 plants per hectare. The seedlings of the *Miscanthus* hybrid were obtained from Austria. They were grown up to 2–4 leaves using the vegetative propagation method – chopped rhizomes. Two plants were planted per square meter, 20 thousand plants per hectare. *Sida* crop was established by planting 2 plants per square meter in rows with inter-row spacing of 1m. *Artemisia vulgaris* planting material was collected from the adjacent crop rotation stands. *Artemisia dubia* was planted using the vegetative propagation method – chopped rhizomes. *Helianthus* was planted by tubers - 2 tubers per square meter, 20000 seedlings per hectare with 1 m inter-row spacing. Indigenous (local) plants – perennial grasses were sown by a drill with 15 cm inter-row spacing. The experiment was designed as a randomized complete block with three replicates. Plot size was 10x10m. Harvested plot size - $10m^2$.

$P_{60}K_{60}$ fertilization was applied on all the area before planting. In the first year, N_{60} was applied as a started to stimulate growth. In the second year, nitrogen fertilization scheme N_0, N_{60}, N_{120} was developed. Nitrogen fertilization was continued each year after resumption of vegetation. Indigenous grasses were cut 3 times, *Panicum virgatum* 2 times. Other plants were cut once in October. Forest plants (*Salix viminalis, Populus tremula x P. tremuloides, Populus nigra)* were cut after 3 growing seasons late in the autumn (in November) in 2010.

Total C and N content of samples was determined simultaneously by dry combustion (Dumas method) using Vario *EL* III *CNS*-autoanalyser (Elementar, Germany). The water soluble carbohydrate (WSC) content was determined using anthrone method. The samples were also subjected to the fibre component analyses: acid detergent fibre (ADF) and neutral detergent fibre (NDF) and acid detergent lignin (ADL) using cell wall detergent fractionation method according to Van Soest. ADF extraction was done on an ANKOM220 Fibre Analyzer (ANKOM Technology 05/03, Macedon, NY, USA) using F57 filter bags (25-µm porosity).

The air temperature during the growing season of the experimental years (2010-2011) exceeded the long-term averages. In 2010, abundant rainfall was also characteristic of the entire growing season. As a result, conditions were conducive to plant growth. In 2011, the spring and early summer were droughty. Due to the shortage of moisture the plants wilted a little. In both experimental years the winters were cold and snowy.

Results and discussion

The dry matter (DM) yield of plant biomass is an important factor for bioenergy production. Herbaceous plants' dry matter yield was highly dependent on the amount of precipitation. Due to the wet spring and summer of 2010, herbage dry matter yield was nearly twice as high as that in 2011. Droughty spring significantly reduced the yield also of those grasses that are cut only once (*Sida, Artemisia dubia*). The dry matter yield of herbaceous plants that do not fix nitrogen depended on fertilization. Not all the grasses responded identically to nitrogen fertilization. Unfertilized *Sida and Artemisia dubia* produced a dry matter yield of 10.5 – 11.2 t ha^{-1}. However, the highest yield 13.29 t ha^{-1} was produced by unfertilized legume *Galega*. The data averaged over two years showed that

Table 1

The potential of biomass dry matter yield and biometrical data of herbaceous plants, average 2010-2011

Plant	Fertilization	Dry matter yield t ha^{-1}	Dry matter %	No. of shoots/ plants	Length of shoots, cm
Sida hermaphrodita	N60	9.58	51.0	18	271
Artemisia dubia	N60	11.10	49.9		174
Galega orientalis	N0	10.98	18.2		134
Phalaris arundinacea	N120	9.89	31.0		135
Silphium perfoliatum	N60	7.29	38.5	33	208
Helianthus tuberosus	N60	8.56	40.7	81	153
Miscanthus giganteus	N120	7.14	52.1	18	235
Dactylis glomerata	N120	6.14	21.2		110
Panicum virgatum	N120	4.62	26.2		105
Polygonum japonica hybr.	N0	8.74	36.2	10	221
Polygonum sachalinensis	N0	5.13	35.8	7	273
Artemisia vulgaris	N60	3.40	59.5		114
Medicago sativa	N60	6.16	25.3		85
Onobrychis viciifolia	N60	5.21	33.9		75
LSD_{005}		**1.814**			

the highest dry matter yields 11.10-10.98 t ha^{-1} were produced by *Artemisia dubia* and *Galega orentalis,* respectively (Table 1). *Artemisia dubia* was cut only once at the end of vegetation. The fresh mass cut at that time contained 49.9 % of dry matter. Similar amounts of dry matter are accumulated also by short vegetation forest plants that can be used for combustion like *Artemisia dubia.* In our previous research, *Artemisia dubia,* fertilized with N_{60} produced a dry matter yield of 15.6 t ha^{-1} already in the second year of growth. Compared with *Galega orentalis*, *Artemisia dubia* developed much more rapidly and produced a high stand density, which prevented weeds from being established. *Galega* is superior to *Artemisia* in two aspects: it does not need nitrogen fertilization and is easier to establish. *Artemisia dubia* does not mature seed and can be propagated only vegetatively by planting fine-cut rhizomes.

Another two plants promising for bioenergetics are *Sida hermaphrodita* and *Phalaris arundinacea.* Their dry matter yield when fertilized with $N_{60\ -120}$ amounted to 9.58-.9.89 t ha^{-1}. *Sidos* plants cut once were the tallest (271 cm) of all plants. They would suit for direct combustion, since their biomass accumulates 51.0 % of dry matter. In terms of dry matter yield, the other tested plants *Helianhtus*, *Miscanthus* (8.56-7.14 t ha^{-1}), significantly lagged behind the above-discussed plants. *Miscanthus,* which is a subject of great interest in West Europe, in our research, in the 3rd -4th year of use when fertilized with N_{120} produced around 7.0 t ha^{-1} of dry matter. The highest yield (11.53 t ha^{-1}) was obtained in the second year of use (Kryževičienė et al. 2011). Due to the cold winters of 2010 and 2011, *Miscanthus* markedly thinned out. In the spring of 2010, the plants that survived accounted for 54 % of the initial number planted. *Miscanthus* does not mature seed. It is commonly propagated by vegetative method and by planting fine-cut rhizomes. Our test material was obtained from Austria. In Lithuania, *Miscanthus* research should be continued. Other tested plants from *Polygonum* genus are invasive and their propagation in Lithuania is not recommended. Unfertilized they produce a biomass yield of 5.14-8.74 t ha^{-1}. Traditional legumes *Medicago sativa* and *Onobrychis viciifolia* yielded well and surpassed some of the imported plants at least in the first year of use.

When cut 3 times, traditional legumes (*Galega, Onobrychis, Medicago*) accumulated the largest content of nitrogen in dry biomass (Table 2). Traditional grasses contained 2-3 times less nitrogen than legumes. Grasses that accumulate more nitrogen and are cut more frequently are better suited for biogas production than for direct combustion. The C:N ratio also indicates the suitability of grasses for biogas production. For the anaerobic biomethane process to be optimal, carbon to nitrogen ratio (C:N) in biomass is one of the main quality indicators. Literature sources indicate various ranges of C:N values. It is maintained that its optimal value commonly ranges between 20 to 30 (Cotana and Giraldi, 2007); however, some authors showed this value to range from 15 to 30 (Osman et al., 2006). In our study, in the biomass of traditional herbs the range of carbon to nitrogen ratio varied from 15.3 *(Galega)* to 51.5 (*Phalaris).* Thus, according to this indicator, *Phalaris* is better suited for combustion than for biogas production. *Sida and*

Table 2

Chemical composition of the above ground biomass of herbs, 2010

Fertilization	Chemical composition %								
	N	C	S	C:N	Fibre		Ash	Lignin	WSC*
					NDF	ADF			
Imported plants									
Sida hermaphrodita									
N_0	0.247	47.2	0.046	194.8	82.8	73.5	3.17	12.7	1.54
N_{60}	0.412	47.1	0.046	129.7	79.6	69.3	4.23	11.8	2.18
N_{120}	0.352	47.6	0.045	136.3	81.1	71.4	3.86	13.3	1.44
Silphium perfoliatum									
N_0	0.630	43.2	0.041	75.0	65.1	56.6	13.10	13.8	2.63
N_{60}	0.411	45.1	0.040	124.4	70.7	63.9	9.18	13.0	1.93
N_{120}	0.448	45.7	0.037	102.1	73.7	67.7	7.00	12.1	1.88
Polygonum sachalinensis									
N_0	0.266	47.0	0.037	177.1	91.9	55.5	6.61	19.1	10.50
Polygonum japonica hybrid									
N_0	0.527	47.4	0.034	89.9	69.6	68.3	4.84	20.6	2.60
Miscanthus giganteus									
N_0	0.798	46.8	0.044	62.2	74.3	50.7	4.90	8.4	7.98
N_{60}	0.734	46.2	0.038	63.2	70.0	49.5	3.61	8.2	5.00
N_{120}	0.515	48.2	0.040	97.9	78.5	57.3	2.80	11.7	5.87
Non-traditional plants									
Artemisia vulgaris									
N_{60}	0.455	48.4	0.048	107.6	74.2	66.0	3.95	16.8	3.24
Artemisia dubia									
N_0	0.372	49.3	0.048	135.0	70.1	62.7	4.22	14.6	3.72
N_{60}	0.355	48.9	0.043	138.7	63.4	58.1	4.17	14.0	6.25
N_{120}	0.420	48.8	0.042	117.8	70.1	64.2	4.26	16.4	2.96
Helianthus tuberosus									
N_0	0.715	46.0	0.057	65.1	58.5	48.5	6.15	10.6	13.35
N_{60}	0.505	46.4	0.050	92.6	57.5	50.8	4.97	10.1	19.10
N_{120}	0.525	46.0	0.047	87.8	56.2	47.7	4.61	8.9	19.70
Local plants									
Dactylis glomerata									
N_0	1.720	43.6	0.168	25.4	55.5	44.5	12.95	14.3	5.95
N_{60}	1.725	44.5	0.202	25.9	58.4	45.6	11.15	16.1	5.12
N_{120}	1.725	45.5	0.124	26.4	57.5	38.3	9.35	9.9	6.99
Phalaris arundinacea									
N_0	0.974	44.4	0.249	45.6	58.4	39.9	9.76	7.8	9.54
N_{60}	0.964	45.3	0.230	47.2	61.7	40.0	8.81	7.2	9.81
N_{120}	0.891	45.9	0.273	51.5	64.1	42.8	7.81	8.5	10.27
Galega orientalis									
N_0	3.010	46.1	0.084	15.3	59.2	49.2	9.32	15.4	3.67
Medicago sativa									
N_0	2.365	47.0	0.088	20.20	57.5	49.1	7.67	16.2	5.18
Onobrychis viciifolia									
N_0	2.59	47.1	0.170	18.2	57.9	48.3	8.07	19.2	4.62

*water soluble carbohydrates (WSC)

Table 3

Biomass yield of forest plants, kg ha^{-1} and biometrical data, 2010

Plant	Fertilization	Fresh mass. kg ha^{-1}	Dry matter yield kg ha^{-1}	DM %	No. of shoots / plants	Viable shoots/ plants	Length of shoots cm	Diameter. shoot cm
Salix viminalis	N0	65482	36474		8.2	3.9	570	2.54
	N60	58667	32678	55.7	7.9	5.5	583	2.74
	N120	68445	38124		8.4	4.4	595	2.95
$LSD_{0.05}$		**9741.3**	**5425.8**		0.74	0.83	20.9	0.14
Populus nigra	N0	51333	27053		11.5	11.5	473	2.71
	N60	62667	33025	52.7	12.7	12.7	468	3.50
	N120	45667	24066		10.2	10.2	458	2.83
$LSD_{0.05}$		**16265.6**	**8571.9**		2.10	2.10	21.0	0.26
Populus tremula x P.tremuloides	N0	33000	18744		1.9	1.9	426	3.62
	N60	39000	22152	56.8	3.0	3.0	421	3.16
	N120	27333	15525		2.2	2.2	391	3.00
$LSD_{0.05}$		**8202.7**	**4659.1**		**1.31**	**1.31**	**30.0**	**0.22**

Table 4

Chemical composition of forest plants, 2010

Fertilization	Chemical composition %								
	N	C	S	C:N	Fibre		Ash	Lignin	WSC*
					NDF	ADF			
Salix viminalis									
N_0	0.485	49.5	0.043	113.9	79.4	16.4	4.93	16.8	4.95
N_{60}	0.559	49.7	0.042	89.4	83.4	18.8	4.95	18.0	4.51
N_{120}	0.480	49.3	0.040	104.8	82.6	17.5	4.77	17.5	4.12
Populus tremula x P. tremuloides									
N_0	0.749	50.0	0.046	66.8	67.4	57.3	2.62	14.3	6.95
N_{60}	0.637	49.1	0.043	77.2	68.3	58.9	2.24	16.6	7.03
N_{120}	0.771	49.4	0.045	64.2	69.6	58.1	2.77	15.5	6.80
Populus nigra									
N_0	0.658	49.1	0.045	76.9	75.1	69.8	2.58	19.4	5.26
N_{60}	0.674	49.4	0.046	75.2	71.3	66.3	3.01	19.1	6.23
N_{120}	0.596	49.3	0.043	84.9	76.4	69.7	2.51	19.2	5.09

*water soluble carbohydrates (WSC)

Artemisia accumulated the lowest levels of nitrogen in dry matter, which confirms their suitability for direct combustion. Higher sulphur contents accumulated in traditional grasses that were cut more frequently. The lowest sulphur contents were accumulated in *Artemisia, Miscanthus, Silphium* and *Sida* plants. Elevated sulphur contents in the biomass are undesirable, especially if it is used for combustion, because sulphur compounds which form in the smoke pollute the environment. NDF is a very important component showing biomass suitability for bioenergetics. The highest fibre content was accumulated in the biomass of *Sida* and *Miscanthus*. It is natural that the more frequently the grass is cut, the less fibre it contains. Lignin, a constituent of fibre, is undesirable in the biomass intended for biogas production. Its highest content was found in the plants *Polygonum* genus and in the biomass of *Onobrychis.* Higher contents of soluble carbohydrates accumulated in *Helianthus tuberosus* (13.3-19.7 %) and traditional grasses (3.6-10.7 %). Soluble carbohydrates increase biogas yield. Ash is unwanted in the biomass intended for combustion.

The lowest ash contents (2.80 - 4.90 %) were accumulated in the biomass of *Sida* and *Miscanthus*.

Nitrogen fertilization had little effect on the chemical composition of biomass. There were found larger differences in chemical composition between species.

After three years of cultivation, short-rotation forest plants were cut after leaf-fall in November 2010. Over the three years, the highest dry matter content (32.7-38.1 t ha^{-1}) in the biomass was accumulated by *Salix viminalis*, while the lowest content (15.5.-22.1 t ha^{-1}) was accumulated by *Populus tremula x P.tremuloides* (Table 3).

Compared with the best-yielding herbaceous plants (*Artemisia dubia, Galega, Sida),* biomass yield was similar. What plants to grow will depend on specific needs and circumstances. Nitrogen fertilization did not give any significant increase in the biomass yield of short-rotation plants. This can be explained by the fact that forest plants were grown in nutrient-rich arable land.

The cut woody plants contained 52.7-56.8 % of dry matter. The tallest plants (595-570 cm) were *Salix viminalis*. The greatest number of stems per bunch (10.2-12.7) was found for *Populus nigra.* Nitrogen fertilization significantly increased stem diameter for *Salix viminalis.*

The lowest nitrogen content (0.48-0.56 %) was accumulated in *Salix viminalis* dry biomass (Table 4). The C:N ratio in its biomass was the highest. The *Salix viminalis* biomass also contained the highest concentration of fibre (NDF) 79.4-83.4 %. However, it contained a fairly high level of ash 4.77-4.95 %.

According to ash content, *Salix viminalis* biomass compared to that of *Artemisia dubia*. The lowest ash content was found in *Populus tremula x P. tremuloides* biomass. This can be explained by the fact that *Populus tremula x P. tremuloides* had the fewest but thick stems. Thus there was relatively lower content of bark in the biomass compared with other tree species.

Higher soluble carbohydrate contents were also accumulated here. Carbon and sulphur contents were similar in the biomass of all tree species. Nitrogen fertilization did not have any significant effect on the chemical composition of tree biomass.

Conclusions

Research into the biomass accumulation in various plants showed that in the imported plants' group, the highest dry matter yield (9.58 t ha^{-1}) was produced by *Sida hermaphrodita* when cut once. Other plants of this group were less productive: dry biomass yield of *Silphium perfoliatum* was 7.29 t ha^{-1}, of *Polygonum japonica, Polygonum sachalinensis* 8.74-5.13 t ha^{-1}, respectively. Of the non-traditional plants, the highest biomass content was accumulated by *Artemisia dubia* (11.10 t ha^{-1}) and *Helianthus tuberosus* (8.56 t ha^{-1}), *Artemisia dubia* biomass was 3.3 times as high as that of *Artemisia vulgaris*. In the group of local plants, unfertilized *Galega orientalis* produced 10.98 t ha^{-1} of dry biomass over 3 cuts. *Phalaris arundinacea,* fertilized with N_{120} kg ha^{-1}, produced 9.89 t ha^{-1}.

Forest plants were cut after 3 growing seasons. The largest amount of dry biomass was produced by *Salix viminalis* 32.7-38.1 t ha^{-1} and *Populus nigra* 24.0-33.0 t ha^{-1}. When forest plants were grown in arable land, nitrogen fertilization had little effect on biomass yield, a biomass reduction trend was observed at fertilizing with N_{120} kg ha^{-1},. *Salix viminalis* also had low nitrogen and sulphur contents. *Salix viminalis* was best suited for combustion.

The amounts of biomass produced by the best-yielding herbaceous plants were similar to those produced by short-rotation forest plants. The choice of plants intended for bioenergetics will depend on specific local conditions, needs and circumstances.

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THE ASSESSMENT OF LINSEED VARIETY 'SCORPION' FOR SUITABILITY FOR BIOFUEL PRODUCTION

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Abstract
In the research, possibilities of linseed as a fuel constituent were evaluated by the following indicators: carbon content, sulphur content, and gross calorific value. The object of the research was the linseed variety 'Scorpion'. The trials were carried out in humi–podzolic gley soil during the period 2008-2010. Complex fertilizer was applied before sowing; N fertilizer rates – N0 kg ha^{-1} as control, N60, N80, and N100 kg ha^{-1}. The research shows ($p<0.001$) that the sulphur and carbon content and the highest calorific yield are influenced by the agrometeorological conditions of the growth year and by the N fertilizer. Various plant sections (stems, shives, and the chaff) were observed to have differing carbon and sulphur contents. Regarding the data of calorific yield results from one hectare, the year 2009 was more favourable than 2010. Taking all factors into consideration, for solid fuel output it is best to use linseed residue material.
Key words: *Linum usitatissimum* L., carbon, sulphur, gross calorific value.

Introduction

Worldwide, linseed is mainly grown for the seed. From the stems technical fibre is obtained, but from the residue material – the shives and chaff – it is possible to obtain solid fuel. The shives are obtained from the woody part of the flax. The shives can be used for insulation material production, also there exist other uses, for instance, adding them to chipboards or as shives for animal bedding. Also the question of using the shives as a fuel is an interesting possibility, as from 2 kg of shives it is possible to obtain the same amount of calorific yield as from 1 litre of heavy fuel oil. The flax shives are characterized by a high lignin (23-31%) content, as well as cellulose (53%) and hemicellulose (24%) content (Tamaki and Mazza, 2010; Ross and Mazza, 2010). In Lithuania (Груздевене et al., 2009) and also in Latvia at the present moment the residue from linseed is ploughed back into the soil or burnt on the field.

The aim of the research was to evaluate the possibilities of linseed variety 'Scorpion' for biofuel production.

Materials and Methods

Annual crop – linseed (*Linum usitatissimum* L.) from *Linacea* family – was tested in the locations and under the conditions described in Table 1. The nitrogen supplementary fertilizer and agrochemicals were given to the linseed in the fir-tree phase (GS 4) (Growth Stages by Turner), and insecticide – at GS 1 and GS 4.

The meteorological conditions for the growth of linseed are shown in Figure 1. In all three growth years the hydrothermal coefficient (HTC) of Selianinov was slightly above 1.5, but the plant germination conditions were not favourable in 2008-2009.

HTC calculated by formula (Čirkovs, 1978):

$$\text{HTK} = \frac{\sum N}{\sum t_{>10^0 C}} \times 10\,; \qquad (1)$$

where

$\sum N$ – sum of precipations for a month, mm;

$\sum t_{>10}$ – sum of temperature above 10°.

Criteria:

HTK ≤ 0.5 – strong, very strong drought;
HTK = 0.6 – weak drought;
HTK ≤ 0.7 – dry conditions;
HTK ≥ 1.0 – characterizes the sufficient moistening.

The linseed samples were harvested by hand in the growth stage of the early yellow ripeness. The plants were tied up in bundles and left to dry in the field for 5-8 days. When flax was dry, it was crushed with the machine Eddi, and after that the pods were cleaned through a shive. The seeds were cleaned with a sample cleaner MLN, weighed (accuracy ± 0.001 g) and the seed yield was established taking 100% purity and 9% moisture content. The sample of 10 g of stems was weighed (accuracy ± 0.0001 g), then scutched with the tool ЛМ-3, broken and shaken until the shives were withdrawn, and weighed again. The result was calculated by the formulae according to the Practicum of crop (Freimanis et al., 1980).

The following parameters were tested: 1) the carbon content in shives, according to standard ISO 625; 2) the sulphur content, according to standard ISO 334; 3) the gross calorific value ($Q_{gr.d}$) with V (volume)=constant for dried fuel at 105ºC, according to standard LVS CEN/TS 14918.

Table 1

Trial methods of the linseed variety 'Scorpion'

Parameters		Trial year		
		2008	2009	2010
Soil type		Humi-podzolic gley soil		
Soil composition	pH	7.3		7.0
	OM, %	3.8 (Tyurin's method)		6.5 (Tyurin's method)
	P, mg kg^{-1}	36 (DL method)		63 (DL method)
	K, mg kg^{-1}	54 (DL method)		98 (DL method)
Pre-crops		Spring rape		Winter wheat
Complex fertilizers	N:P:K, kg ha^{-1}	6:11.3:24.9, total 300 (N=29.03; P=54.9; K=120.5)		
Sowing time		9th May	4th May	6th May
Sowing rate	kg ha^{-1}	70		
N fertilizer rate	kg ha^{-1}	N0, N60, N80, N100		
Picking dates		29th August	28th August	10th August
Threshing dates		23rd September	21st September	20th September
Trial plots	m^2	7.5		
Replication		4		
Agro-chemicals	Insecticide	Fastaks 50 e.c. (alfa- cipermetrin, 50 g L^{-1}) 0.3 L ha^{-1}		
	Herbicide	Glins 75 d.g. (hlorsulfuron, 750 g kg^{-1}) 10 g ha^{-1}		
		Lontrels 300 s.c. (klopiralid, 300 g L^{-1}) 0.3 L ha^{-1}		MCPA Super 500 s.c. (MCPA, 500 g L^{-1}) 1.0 L ha^{-1}

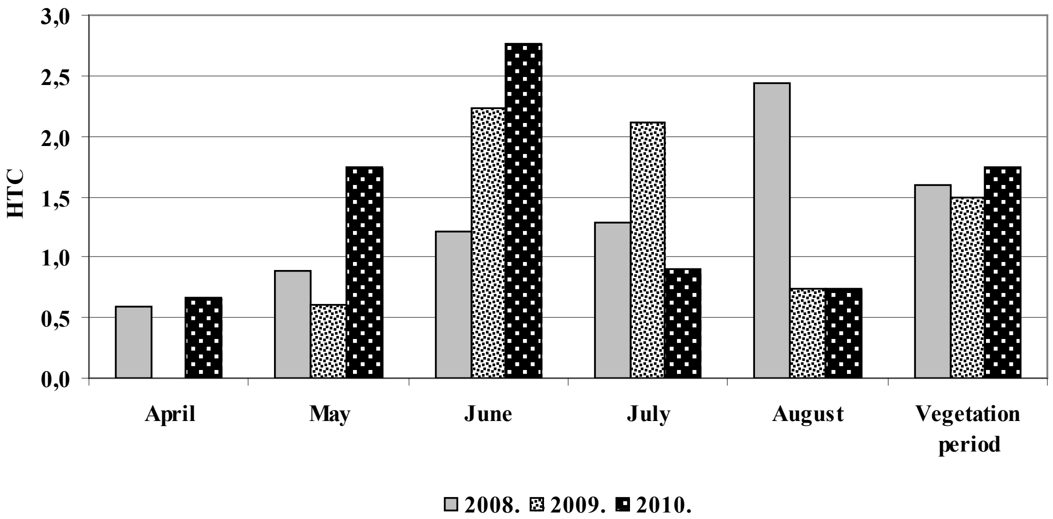

Figure 1. **Water stress expressed as hydrothermal coefficient (HTC) in Viļāni in 2008-2010.**

The MS Excel programme was used for data statistical processing. The statistical evaluation of data was carried out by using methods of correlation and regression, as well as dispersion analysis, and descriptive statistics (Доспехов, 1985; Arhipova and Bāliņa, 2003).

Results and Discussion

Carbon is the main burning element in fuel. The carbon content (min – average – max) was established for the linseed stems (0.39 – 0.43 – 0.47 g kg^{-1}), shives (0.38 – 0.40 – 0.44 g kg^{-1}) and chaff (0.40 – 0.43 – 0.48 g kg^{-1}) (Fig. 2). In 2008 and 2010, the greatest carbon content was in the flax stems (0.45 g kg^{-1} and 0.44 g kg^{-1}), in 2009 - in the chaff (0.44 g kg^{-1}). Analysis of the influence of N fertilizer on the content of carbon showed that highest C content in stem and shaff was obtained after applying N0 and N60 kg ha^{-1}, but in shives – after application of N60 kg ha^{-1}.

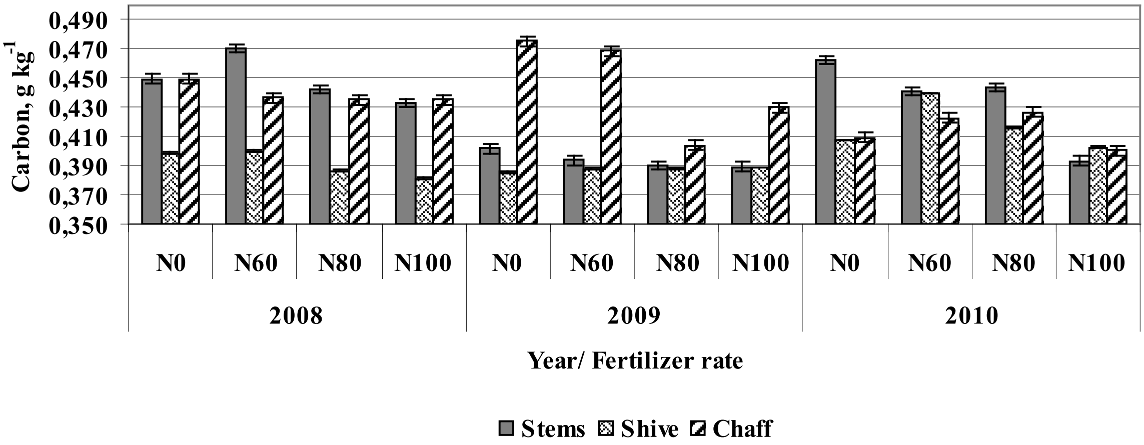

Figure 2. **Carbon content depending on the linseed growing year, and N fertilizer rates**

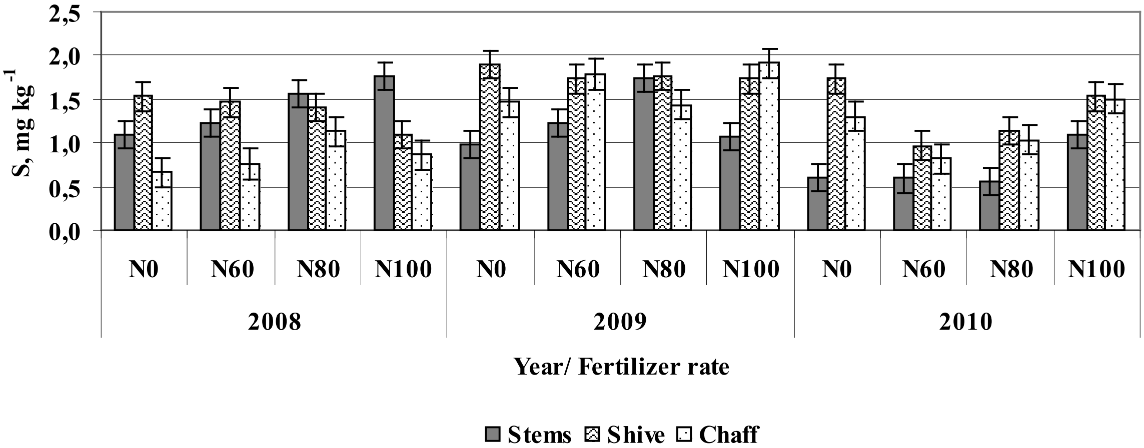

Figure 3. **Sulphur (S) content depending on the linseed growing year, and N fertilizer rates**

The calorific value from sulphur burning is low – 9300 kJ kg^{-1}, therefore the value for it as a burning element is low, and sulphur is an unwanted and harmful component in fuel, as it produces in the boiler surface heat and other energy equipment corrosion (Cars, 2008). The sulphur content (min – average – max) was established for the linseed stems (0.56 – 1.13 – 1.77 mg kg^{-1}), shives (0.97 – 1.50 – 1.90 mg kg^{-1}) and chaff (0.66 – 1.22 – 1.91 mg kg^{-1}) (Fig. 3). In 2008, the greatest S content was in the flax stems (1.42 mg kg^{-1}), in 2009, in the chaff (1.78 mg kg^{-1}), and in 2010 - in the shives (1.34 mg kg^{-1}). It can be seen that for flax stems and chaff the greatest S content was found after application of N 100 kg ha^{-1}, for the shives – N0 kg ha^{-1}. Linseed hybrids grown in Latvia have up to 1.0 mg kg^{-1} sulphur content in the shives using the fertilizer rate of N60 kg ha^{-1} (Komlajeva et al., 2011), which means that the sulphur content can be determined by the chosen variety.

For the linseed variety 'Scorpion', the sulphur and carbon content and the gross calorific yield in various plant sections were dependent on the growth year and N fertilizer rate (Table 2).

In our research the influence of N fertilizer is not unequivocal. In other research (Vucāns, 1996) it has been found that the fertilizer can increase the productivity and can reduce the energy indicators. In 2010, HTC variances were observed in the flowering stage of linseed - due to excessive rainfall in June, and rainfall deficit and temperatures above 30 °C in July (Fig. 1). Scientists Ivanovs and Stramkale (2001) have observed that precipitation requirements for flax are relatively great and temperature requirements are modest.

Our research showed a significant negative correlation ($p<0.05$) between sulphur (y) and carbon (x) content in the shives of linseed (Fig. 4). In the shives and stems of the linseed, a weak correlation ($p>0.05$) was observed between sulphur and carbon. That confirms that each part of a plant has a different chemical composition. The feed availability in plant is dependent on the soil quality, the fertilizer usage, and weather conditions (Hiltunen et al., 2008).

Table 2

The influencing factor proportion (p<0.001) on the carbon and sulphur content and gross calorific value of the linseed variety 'Scorpion', η, %

Plant part	Factor	Carbon content	Sulphur content	Gross calorific value
Stems	Growth year (A)	65.7	51.8	95.4
	Nitrogen fertilizer (B)	19.3	18.8	1.1
	Interaction (A x B)	14.8	25.4	3.1
Shive	Growth year (A)	64.6	45.7	47.0
	Nitrogen fertilizer (B)	17.3	19.3	12.8
	Interaction (A x B)	18.1	28.1	38.6
Chaff	Growth year (A)	33.4	66.8	–
	Nitrogen fertilizer (B)	23.5	9.1	–
	Interaction (A x B)	42.5	19.9	–

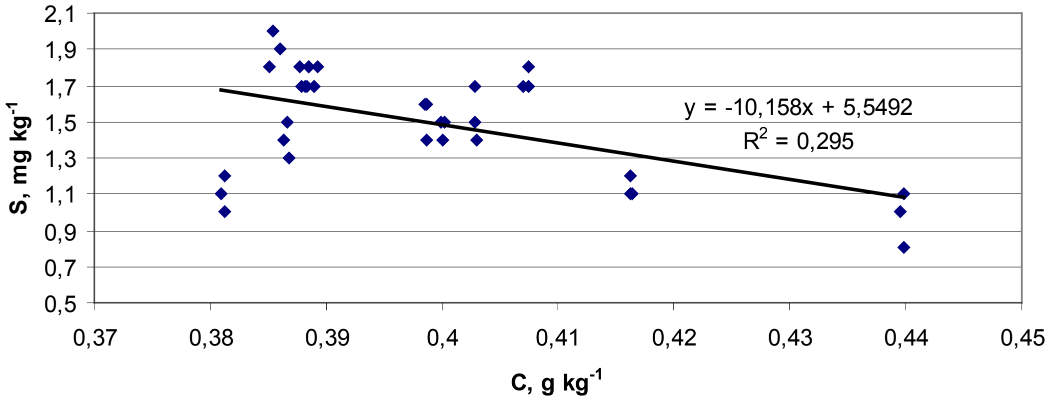

Figure 4. **Sulphur (S) content depending on carbon (C) content in shives of the linseed variety 'Scorpion', 2008-2009 (p<0.05; n=36: r=0.54)**

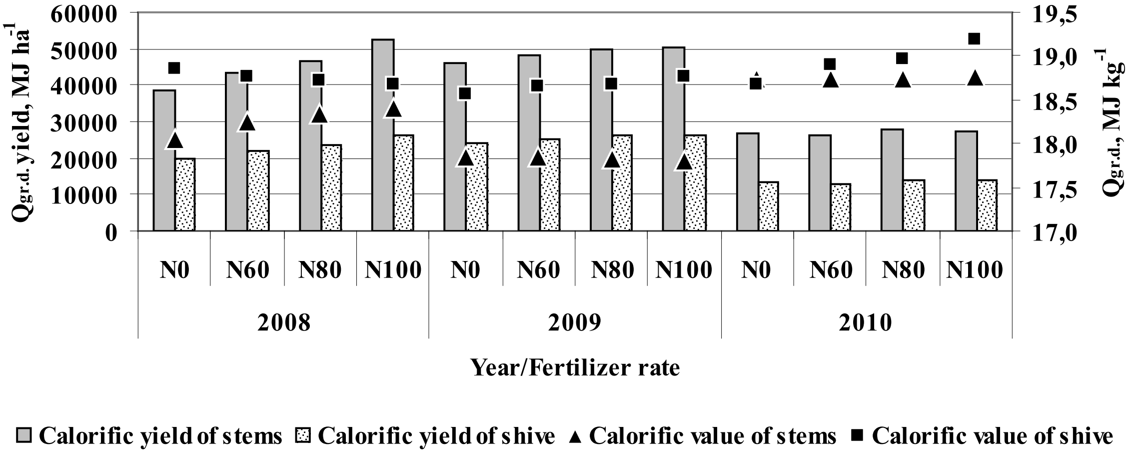

Figure 5. **Calorific yield and value depending on the linseed growing year, and N fertilizer rates**

The heat from fuel burning is a basic quality indicator. The German standard DIN 51731 indicates that the calorific value would reach at least 17.5 MJ kg^{-1} (Tardenaka, Spince, 2006), but in 2010 the gross calorific value for the linseed shives varied from 18.2 to 19.4 MJ kg^{-1} (Poiša, Adamovičs, 2011a) and 18.7–20.2 MJ kg^{-1} (Komlajeva et al., 2011). The gross calorific value (min – average – max) of linseed variety' 'Scorpion' is shown in Figure 5: for the linseed stems (17.75 – 18.28 – 18.79 MJ kg^{-1}), for the shives (18.56 – 18.78 – 19.23 MJ kg^{-1}). In all research years the highest calorific value was observed for the linseed shives. In 2009 the calorific value was lower than in 2008 and 2010, but the productivity was greater.

The research showed a significant positive correlation ($p<0.05$) between the gross calorific value and the carbon content in the linseed 'Scorpion' stems ($p<0.05$; $n=36$; $r=0.52$) and shives ($p<0.05$; $n=36$; $r=0.56$).

The linseed gross calorific value in our research was found to be similar to that of other plants: 1) in winter crops (triticale, winter rye, winter wheat) the straw has a higher calorific value than the grain, for example, for straw the highest calorific value has been determined – 16.39 MJ kg^{-1}, the net calorific value – 14.75 MJ kg^{-1} (Kaķītis et al., 2009), 2) for hemp variety 'Bialobrzeskie' the gross calorific value has been determined 17.76–18.98 MJ kg^{-1}, and net calorific value – 15.03–16.14 MJ kg^{-1} (Poiša, Adamovičs, 2011b), 3) for the dry matter of sunflower briquette – 17.07–17.37 MJ kg^{-1}, but for briquettes from dioecious and monoecious hemp a slightly lower calorific value was determined 16.60–16.74 MJ kg^{-1} and 16.56–16.64 MJ kg^{-1} respectively (Alaru et al., 2011). Linseed residue material can be used for the production of solid fuel, even though the stem crop, compared to other energy-producing plants, is small.

Conclusions

For the linseed variety 'Scorpion', the sulphur and carbon content and the highest calorific value in various plant parts was dependent on the growth year and the nitrogen fertilizer rate. Carbon content (min – average – max) in various was similar – stems (0.39 – 0.43 – 0.47 g kg^{-1}), shives (0.38 – 0.40 – 0.44 g kg^{-1}) and chaff (0.40 – 0.43 – 0.48 g kg^{-1}).

Sulphur content (min – average – max) in linseed production differed – stems (0.56 – 1.13 – 1.77 mg kg^{-1}), shives (0.97 – 1.50 – 1.90 mg kg^{-1}) and chaff (0.66 – 1.22 – 1.91 mg kg^{-1}).

The gross calorific value (min – average – max) was observed in the linseed stems (17.75 – 18.28 – 18.79 MJ kg^{-1}) and shives (18.56 – 18.78 – 19.23 MJ kg^{-1}).

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ENERGY-SAVING TECHNOLOGY OF MAIZE GRAIN CONSERVATION IN BIG-BAGS

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Abstract
Introduction. Highly productive livestock production is mainly based on the use of maize grain in feed balance. Maize makes up nearly one third of the world grain production. In Ukraine annual demand for maize grain for forage purposes is 5-6 mln t. It should be emphasized that maize is a crop harvested during autumn period and its grain always has high moisture content, thus it requires appropriate conservation technologies. One of them is a technology of damp grain conservation in big-bags as it does not require costs on energy sources for drying.
Methodology. The technology of damp grain conservation is based on its storage in oxygen-free environment with preservative.
It is fulfilled in the following way: just after threshing, damp (24–38%) maize grain is supplied at barn floor where big-bags are filled together with application of the biological preserving mixture, air exhaustion, hermetization by means of soldering of the liner neck and stacking for further storage.
Results. After continuous storage grain was of high quality. Its feeding to milk cows in the diets gave 0,96 kg yield increase in the milk with basic fat content (3,4%), i.e. +5,14 % to control, where dried grain was fed.
Economic calculations on the expediency of damp maize grain drying show that a farm applying the technology of damp maize grain conservation in big-bags has 14,13 $/t losses, but when drying at **МХП,** losses make up 33,04 $/t, in other words, the farm saves only when it stores 18,92$/t of grain. Besides considering better productive effect of conserved damp grain when fed to milk cows, the economic effect of one ton is $120 because of the obtained additional quantity of milk with basic fat content. General effect makes up 138,92 $/t of conserved damp maize grain.
Conclusions. Usage of the offered technology allows making the conserved damp grain a commodity, i.e. it can be transported at any distances at the same time preserving its nutritious value and avoiding energy costs on grain drying.
Key words: corn, wet corn, dry grain, milk, economy, energy.

EFFECT OF SOIL TILLAGE AND HERBICIDES ON THE GRAIN MAIZE YIELD UNDER CONDITIONS OF THE FOREST-STEPPE ZONE OF UKRAINE

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Abstract

Introduction

Food production has always been one of the global problems. Recently it has become even more urgent due to development of the programs on the fuel production from crops. Under such conditions domestic commodity producers are interested in intensification of the output of food and fodder grain as a demand for food products, fodders and bio raw materials is growing. Maize is one of the leading crops which grain is used for biofuel (ethanol) production. In recent years areas under this crop in Ukraine have grown up to 3,6 mln ha, and grain production exceeded 18 mln t. The problems of increase of maize productivity and search of the ways of reduction of energy costs for its production, mainly introduction of no-till technology, are still very urgent for the farmers.

Materials and Methods

Field trials were carried out in 2010-2011. The soil of the trial field was grey forest, mid loamy by the mechanical composition with humus content – 2,2 – 2,4 %.

Three methods of soil tillage were researched in the trial:

1. Ploughing at the depth of 20-22 cm; 2. Discking at the depth of 10-12 cm ; 3. No-till.
2. concepts were used for weed control:
    1. Weed control without herbicides
    2. Topramezon 50 a.i. g/L+dicamba 160 a.i. g/L + metolat 1.25 L/ha^{-1}

Results and Discussion

Analysis of research results has shown that the plots had a mixed type of weed infestation before herbicide application (3-4 leaf phase of the crop).

Weed number on untreated plots was 138 per m^{-2}, among them such weeds as *Setsria glauca L.*– 45-76 per m^{-2} and *Echinochloa cruss-galli (L.) Roem.* – 26-45 per m^{-2} dominated. Dicotyledonous weeds were represented by *Chenopodium album L.* – 4-6 per m^{-2}, *Amaranthus retroflexus L.* – 3-5 per m^{-2} . As for perennial species there were *Elytrigia repens L.* – 2-4 per m^{-2} and *Convolvulus arvensis L.* – 1-3 per m^{-2}. Annual weed height was within 1-3 cm, and the height of were *Elytrigia repens L.* was 10-15 cm.

Yield increase 2.49 t ha^{-1} was obtained against a background of ploughing where herbicide Topramezon 50 a.i. g/L+dicamba 160 a.i. g/L + metolat 1.25 L/ha^{-1}at 3-leaf phase of maize was applied.

Conclusions

Efficacy of weed control concept has not been sufficiently different against a background of different methods soil tillage.

Grain maize yield in no-till variant was reliably low than in ploughing.

Keywords: maize, bioenergy, no-till, weed control, herbicides

POLICIES AND MEASURES TO PROMOTE SUSTAINABLE BIOENERGY PRODUCTION AND USE IN THE BALTIC SEA REGION

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Abstract
The Baltic Sea Region can be regarded as a showcase for the sustainable production and consumption of bioenergy and a frontrunner in innovative technological, policy and business solutions. However, there are a number of environmental sustainability risks associated with increased energy uses of biomass from forestry and agriculture, which also in the future need to be adequately addressed by EU and national legislation. Supporting the *sustainable* production and consumption of bioenergy in the Baltic Sea Region has been one of the key rationales of the INTERREG IV B project *Bioenergy Promotion*, which was selected as one of the flagship projects under the EU Strategy for the Baltic Sea Region. The following paper summarizes selected project findings and recommendations derived from the policy related project work.
Key words: Baltic Sea Region, EU policies, national policies, sustainability criteria, support schemes.

Introduction

In most countries of the Baltic Sea Region (BSR), biomass - particularly from forests - is expected to play a key role for achieving the overall national renewable energy targets and sector targets contained in the Renewable Energy Directive (2009/28/EC) and the National Renewable Energy Action Plans. By 2020 the main bioenergy markets of the European Union will be in the BSR: Germany, Sweden, Finland and Poland.

Bioenergy production and consumption are not automatically sustainable and their promotion has to be performed with a sense of proportion. Governments should promote particularly those bioenergy pathways which are contributing in a beneficial way to climate change mitigation and other sustainability goals. The most promising bioenergy pathways from a *Sustainable Development* perspective are those that use locally available biomass residues from forestry and agriculture, by-products from related industries and biogenic waste streams and which employ highly efficient conversion processes and technologies.

The Renewable Energy Directive contains sustainability criteria for biofuels and bioliquids which are binding for all Member states. Biofuels and bioliquids which do not meet those criteria cannot be counted towards the EU's renewable energy targets and national renewable energy obligations or benefit from financial support. These criteria include minimum lifecycle GHG savings of 35 per cent (50-60 per cent from 2017/2018). Furthermore, the raw material shall not be obtained from land with high carbon stock and from land with high biodiversity value. Production of agricultural raw material cultivated in the European Community should comply with EU environmental requirements for agriculture and be in accordance with the minimum requirements for good agricultural and environmental condition.

In its Report on Sustainability Requirements for the Use of Solid and Gaseous Biomass Sources in Electricity, Heating and Cooling (COM(2010)11), the European Commission refrained from extending the binding sustainability criteria applying to biofuels and bioliquids to solid and gaseous biomass used in electricity, heating and cooling. Instead, the European Commission recommended that Member states that either have or who introduce national sustainability schemes for solid and gaseous biomass used in electricity, heating and cooling, ensure that these in almost all respects are the same as those laid down in the Renewable Energy Directive for biofuels and bioliquids. Due to the characteristics of the production and use of solid and gaseous biomass, certain differences were considered appropriate by the Commission. It was recommended to develop an EU-wide harmonised GHG emissions calculation methodology to calculate lifecycle emissions. It was also recommended that the GHG performance criterion is not applied to wastes, but to the products for which default GHG emission values have been calculated as listed in the Annex II of the Commission's report. To stimulate higher energy conversion efficiency, Member states should in their support schemes for electricity, heating and cooling installations differentiate in favour of installations that achieve high energy conversion efficiencies, such as high efficiency cogeneration plants as defined under the Cogeneration Directive (2004/8EC). The Commission also recommended that sustainability schemes apply only to larger energy producers of 1 MW thermal or 1MW electrical capacity or above.

The Commission committed itself to report again by 31 December 2011 on whether national schemes have sufficiently and appropriately addressed the sustainability related to the use of biomass from inside and outside the EU, whether these schemes have led to barriers to trade and barriers to the development of the bioenergy sector. It announced to consider if additional measures such as common sustainability criteria at EU level would be appropriate. However, at the time of editing this paper, the Commission's report was not published yet.

Supporting the *sustainable* production and consumption of bioenergy has been the key rationale of the INTERREG IV B project *Bioenergy Promotion*, one of the flagship projects under the EU Strategy for the Baltic Sea Region. *Bioenergy Promotion* is a project co-financed by the EU and the Norwegian government in the frame of the INTERREG IVB programme. The project has been running from 2009 to January 2012 and serves as a platform for cross-sector and trans-national networking to facilitate information and knowledge exchange and coordinated policy development. The project consortium comprised 33 partners from ten countries of the Baltic Sea Region, Lead partner being the *Swedish Energy Agency*. The operation has been selected as one of the flagship projects under the *Action Plan* accompanying the *EU Strategy for the Baltic Sea Region* COM(2009) 248 final and successfully applied for a 2 years extension stage.

The objective of this paper is to summarize selected findings of the policy related work in *Bioenergy Promotion* which has been coordinated by the German Federal Ministry for the Environment, Nuclear Safety and Nature Protection in co-operation with the Environmental Policy Research Centre at the *Freie Universität Berlin*.

Methods

In a series of two workshops and one cross-fertilization seminar in Sweden and Finland, the project partners commonly developed principles and criteria for *sustainable* bioenergy production in the BSR serving as a guidance to multiple stakeholders including biomass producers and users, investors, NGOs, energy companies, etc. The criteria also aim at supporting public decision makers when developing strategies for sustainable production and consumption of bioenergy and optimizing their policy frameworks and support schemes. These principles and criteria go partly beyond those for biofuels and bioliquids contained in the Renewable Energy Directive, as they apply to all energy uses of biomass (not only biofuels and bioliquids) and include the following items: biodiversity, resource efficiency (including land use), energy efficiency, climate change mitigation efficiency, social well-being and economic prosperity.

The principles and criteria developed in the project remain mostly on a general level. However, in some cases quantitative indicators have been developed. For instance, for solid and gaseous biomass sources used in electricity, heating and cooling, the *Bioenergy Promotion* project partners recommend minimum lifecycle GHG savings of 80 per cent. This ambitious landmark favours the utilization of forest or agricultural residues and precludes pathways using tropical/sub-tropical feedstock, pathways using fossil process fuel, but also a certain pathways utilizing annual energy crops, like maize for biogas.

In a further step the project partners assessed to what extent national policy frameworks and support schemes for bioenergy integrate any sustainability principles and criteria. These assessments consider the following items:

– the transposition and implementation of the binding criteria for biofuels and bioliquids set by the Renewable Energy Directive;
– the recommendations contained in the EU Commission's Biomass Sustainability Report of 2010;
– the principles and criteria developed in the frame of *Bioenergy Promotion* being not or only partly covered by EU legislation (e.g. energy efficiency, resource efficiency).

Finally, the project partners formulated transnational and country-specific policy recommendations.

Results and Discussion

In the following we will focus on the findings related to the use of solid and gaseous biomass for electricity, heating and cooling. We will also provide selected trans-national policy recommendations.

To ensure the sustainable production and use of solid and gaseous biomass, most governments in the Baltic Sea Region rely on sector legislation (e.g. forest legislation, nature protection legislation, cross compliance rules in agriculture). However, *Bioenergy Promotion* also illustrated that those regulations are not always sufficient to prevent undesirable and unsustainable developments due to implementation gaps and lack of enforcement.

None of the governments in the BSR has introduced or is presently planning to introduce any binding sustainability scheme for solid and gaseous biomass sources used in electricity, heating and cooling following the recommendations of the EU Commission contained in the Biomass Sustainability Report of 2010.

In most BSR countries the integration of sustainability principles and criteria into support schemes still plays a marginal role or is in an embryonic stage. Several BSR countries started or plan to integrate sustainability principles into their support schemes for bioenergy. In Germany sustainability principles and criteria have been increasingly considered to amend the support schemes for electricity and heat from biogas (e.g. promoting energy conversion efficiency and resource efficiency).

Most BSR countries have rather effective forest and environmental legislation in place ensuring sustainable forest management and provide good showcases for sustainable forest management certification. Voluntary forest certification systems like the *Forest Stewardship Council* (FSC) and the *Programme for Endorsement of Forest Certification* (PEFC) cover comparatively high shares of the forest area in the BSR, also compared to the EU average. National PEFC or FSC standards occasionally address critical sustainability issues related to wood fuel harvesting (e.g. removal of logging residues, removal of dead wood, stump harvesting), even though not always in a systematic and consistent manner. Furthermore, the sustainability requirements of corresponding national systems show considerable variations.

The project highlighted a number of promising policy approaches supporting sustainable bioenergy production and consumption in the BSR including

- environmental quality objectives in Sweden for forestry and agriculture;
- effective carbon and energy taxation in Sweden, Denmark and Norway;
- wood energy harvesting guidelines in Finland and Sweden;
- integration of sustainability considerations in (sub-)regional policy frameworks (e.g. agreement on sustainable biomass procurement between *Vattenfall Europe* and the Senate of Berlin);
- integration of sustainability considerations into regional support schemes (e.g. in the federal state of *Schleswig-Holstein* in Germany);
- integration of sustainability considerations into national support schemes, for instance:
  - special *boni* for the use of environmentally beneficial raw material like manure or landscape conservation material in the feed in tariff systems of Germany and Latvia (planned);
  - minimum energy efficiency requirements for biomass/biogas plants, e.g. in Finland, Germany, Latvia or Lithuania (planned);
  - CHP bonus in Germany (up to 2011), heat premium for biomass CHP plants in Finland;
  - institutional support for (sustainable) bioenergy production (e.g. Biogas Secretariat in Denmark).

Although the BSR can be regarded a showcase for sustainable bioenergy development, there are certain environmental sustainability risks associated with increasing energy uses of biomass from forestry and agriculture, particularly related to the removal of logging residues like tops and branches, whole tree harvesting, dead wood removal or the production of dedicated energy crops which should be appropriately addressed by legislation and existing certification systems also in the future.

There is already intensive biomass trade among the countries of the BSR (e.g. wood pellet exports from the Baltic countries to Sweden or Denmark). Taking into account information provided in the National Renewable Energy Action Plans, biomass imports are likely to further increase in a number of BSR countries, particularly in Denmark, Germany, and Sweden. It can also be assumed that biomass imports from third countries outside the European Union, particularly the Russian Federation, Belarus, Ukraine and other European non-EU countries, but also from North America and other continents can be expected to grow. In this context, solid biomass imports from countries in Central Africa, South America, or Asia, but also from other non-EU countries might raise significant sustainability concerns due to lacking or insufficient safeguards addressing deforestation and forest degradation or ensuring sustainable forest management.

Diverging government positions exist presently in the BSR concerning the introduction of binding sustainability criteria for solid and gaseous biomass used in electricity, heating and cooling. The Swedish government in liaison with the governments of Finland and the three Baltic countries expressed concerns in view of a binding sustainability scheme for solid and gaseous biomass, whereas the German, Danish and Polish governments favour the extension of the binding EU criteria to cover all energy uses of biomass.

In the absence of a binding sustainability scheme at EU level there is a risk of having a patchwork of potentially diverging sustainability regimes across Europe which might cause insecurity for investors, a potential obstacle to biomass trade, and a ‘race to the bottom’. Project partners also pointed out to the inconsistencies of the current EU policy framework where, for instance, biogas used as a transport fuel is subject to sustainability criteria, but not, if used for electricity or heating and cooling.

Several large power companies in the BSR like DONG, FORTUM, Vattenfall, E.ON and corresponding associations (EURELECTRIC) have been advocating in favour of binding EU criteria for solid biomass favouring a consistent approach. A number of utilities have developed voluntary biomass sustainability standards in the frame of their corporate social responsibility policies. In 2010, the companies mentioned above have launched the *Initiative Wood Pellets Buyers*, a joint business co-operation to facilitate trade between utilities through uniform contracting and a common sustainability approach.

Conclusions

Bioenergy production and use can provide multiple environmental and socio-economic opportunities and benefits (e.g. significant reductions of GHG emissions, improvements in energy security and trade balances, opportunities for economic and social development, particularly in rural communities, mitigation of waste disposal problems and better use of natural and other resources). The BSR can be regarded as a showcase for sustainable bioenergy development and a frontrunner in innovative technological, policy and business solutions.

However, the production, processing, transport and conversion of biomass into energy (e.g. heat and/ or electricity) can also have adverse impacts for GHG balances, biodiversity, natural habitats and ecosystem services, soil and water quality, on a global, regional or local scale. The environmental sustainability risks associated with increased energy uses of biomass from forestry and agriculture need to be adequately addressed by EU and national legislation also in the future.

The promotion of bioenergy production and consumption has to be performed with a sense of proportion. Governments should make sure that policy development always considers full life-cycle impacts as well as direct and preferably also indirect effects of bioenergy production and use. Calculations of GHG emissions should consider not only CO_2 emissions, but also other GHG like e.g. nitrous oxide and methane. Biomass is a renewable but limited natural resource; therefore its use should be as efficient as possible.

A vast majority of project partners agreed that actions should be taken at EU and national levels to enable a level playing field for all biomass applications and to progressively develop a coherent and ambitious set of sustainability criteria for all biomass uses across heat, electricity, transport but also for non-energy uses of biomass. A *Knowledge-Based Bio-Economy* where the same biomass streams will be used increasingly for different applications (as in cascading and multiple uses) requires clear regulations and minimum standards which apply to all uses of biomass.

From a *Sustainable Development* perspective, small to medium sized biomass conversion plants can be regarded as particularly promising options offering multiple potential advantages such as: better use of locally available biomass resources, higher resource efficiency due to better utilization of surplus heat in cogeneration processes, lower energy transmission and distribution losses, better opportunities to close material and nutrient cycles, higher contribution to rural/ regional development.

Promoting sustainable production and use of bioenergy requires an integrated, cross-sector and multi-functional perspective. The *Bioenergy Promotion* project partners emphasized the significance of resource efficient and energy efficient bioenergy production and use, and the project delivered a number of examples for multifunctional and integrated bioenergy systems (e.g. multi-product use, symbiosis systems, integrated wastewater/bioenergy systems, integration of material and energy uses of biowaste through combined fermentation and composting of digestate).

"Systems thinking" across a broad range of sectors and the optimization of material flows including biomass, water, residues, nutrients, digestate, or waste, and energy flows in an integrated manner facilitates the development of sustainable bioenergy systems. Hence, national, regional and local governments should create enabling conditions by facilitating cross-sector networking, information exchange, economic incentives and other instruments.

The integration of sustainability principles and criteria into policy frameworks and support schemes is a novel subject of renewable energy policy and related policy research. The country policy assessments developed in the frame of the *Bioenergy Promotion* project provide valuable insights for national and regional governments, but also for the European Commission which has important monitoring and reporting obligations also covering the development of rules related to the sustainable use of solid and gaseous biomass for electricity, heating and cooling.

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BIO-FUEL FROM ANAEROBIC CO-DIGESTION OF THE MACRO-ALGAE *ULVA LACTUCA* AND *LAMINARIA DIGITATA*

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Abstract
World's energy crisis is becoming increasingly critical when emission from fossil fuel due to the rapid expansion of population and their growing energy consumption is considered. This leads us to reassess the potential of already available renewable energy sources and to step further in the exploration of marine biomass. So far, the progress in treating different groups of algae as a source of energy is promising although their utilization is still in early days. In the present study, green seaweed, *Ulva lactuca* and brown seaweed *Laminaria digitata* was co-digested with cattle manure at mesophilic (35±2°C) and thermophilic (50±2°C) condition for testing the biogas production at lab scale continuous reactors (3.2 liters working volume). Ulva was grown and harvested in Danish algae center and washed to reduce salt concentration and subsequently macerated to facilitate feeding in the digesters. *Laminaria*, however, was harvested from the sea (Fornæs, Denmark) although similar pretreatment method as *Ulva* was followed. The results show that the methane yield of *Laminaria* from mesophilic anaerobic digestion was fairly stable (average 138 lCH4/kgVSadded) over a different type of feeding. Methane generation from thermophilic reactors both for *Ulva* and *Laminaria*, on the other hand, were significantly varied, one opposite to the other, as the feeding rate varied. While the thermophilic treatment of *Laminaria* produced an average of 142 L/kgVS, Ulva yielded around 122 L/kgVS. Overall, it was found that algae are very interesting substrates for utilizing as gaseous bio-fuel through anaerobic co-digestion with cattle manure.
Key words: renewable energy, *Ulva lactuca, Laminaria digitata*, anaerobic digestion, cattle manure.

Introduction

The choice of algae as a bio-fuel is characterized by many fold advantages over conventional biomasses. Firstly, it has a huge potential as the source of energy crops due to its easily hydrolysable sugars and low lignin content (Nkemka and Murto, 2010). Secondly, it yields a higher amount of biomass per unit of light and area and grows in the seawater that saves a lot of agricultural lands which are continuously shrinking due to their use highly limited by the food production. In one study, it was estimated that the potential of algae for producing energy is 100 EJ (Exa-Joule) which corresponded to the land-based biomass was 22 EJ (Chynoweth et al. 2001). Much of these energy potential of seaweeds might be extracted through anaerobic digestion which has been a viable solution over the last few decades. Anaerobic digestion of seaweed, however, is challenged with the issue of inhibition due to the high concentration of sulfur, sodium chloride and heavy metal (Nkemka and Murto, 2010). But within the scenario where macroalgae is considered as a substrate together with the base feedstock such as cattle manure can overcome some of these problems. For instance, average species of macroalgae are rich in carbon content that can contribute to improve the overall C:N ratio while co-digested with basic feedstock (i.e. cattle manure). Additionally, the efficient operation of anaerobic digester can be enhanced by the higher C:N ratio in the range of 20-30 and the higher methane yield in the range of 20-30 m^3 CH_4 m^{-3} as according to the literature study(H.B.Nielsen and S.Heiske, 2012). These values are unlikely to be achieved while the reactor is run by the digestion of cattle manure alone which has the C:N ratio equal to 8-12 and the yields approximately 13-14 m^3CH_4 m^{-3} manure. Considering these, the purpose of this study, therefore, is to evaluate the feasibility of the anaerobic co-digestion of algae (*Ulva lactuca* and *Laminaria digitata*) with cattle manure by conducting experiment in the continuous reactors.

Materials and Methods

Inoculum

This study included both mesophilic and thermophilic inoculum. The thermophilic inoculum was collected from the biogas plant in the research center Foulum, Denmark, which operates with the thermophilic digester at 52±3°C . The measured total solid (TS) and volatile solid (VS) of this inoculum were 2.83±0.5% and 1.43±0.5% respectively, whereas the approximate pH value and total ammonium nitrogen (TAN) were found as 8.12 and 1.82 g/L respectively. The mesophilic inoculum, on the other hand, was collected from the Bårnlev plant, Aarhus, Denmark, that works at 35±3°C with an average TS, VS and ammonia content of 4.4±0.5%, 3.9±0.7%, and 3.8±0.3g/L respectively.

Substrates

Dairy cattle manure

Cattle manure was derived by providing the maize silage as the main feeding to the dairy cattle and was supplied to our facility in the Biogas plant, Foulum research center, Denmark. The 1m^3 container filled with cattle manure was placed inside the indoor storage in august 2011, in the vicinity of experimental premises, maintaining a constant temperature of 15±2 degree Celcius. Manure was supplied with the container as soon as it was generated and underwent no previous storage before delivering to us. The average TS, VS and pH of the cattle manure throughout the entire experimental period was 6.8±0.9%, 5.6±0.6% and 6.8±0.5 respectively.

Ulva lactuca and Laminaria digitata

The *Ulva lactuca* was grown and harvested at the Danish Algae center and *Laminaria digitata* was collected by hand from the sea (Fornæs, Denmark). After harvesting, algae were frozen in plastic bags at -18^{o}C until using for the biogas experiment. *Ulva* was washed by tap water and torn by hand before using for the experiment whereas *Laminaria* was washed by tap water and macerated by the kitchen scissors with an approximate size of 10x10 mm.

Analytical Methods:

Total solids (TS) were measured after heating the samples for 24 hours at 105^{o}C. TS was further heated and incinerated at 550^{o}C for 5 hours to turn into ashes. Volatile solid (VS) was calculated by subtracting the amount of ashes from the amount of TS (Møller et al. 2007). Volatile fatty acid (VFA) was determined by acidifying 1 ml of sample with 4 ml of pivalic acid and subsequently centrifuged for 20 minutes at 12,000 rpm. The centrifuged sample was then filtered to prepare for the Gas Chromatograph (Hewlett Packard 6850A) which analyzed the VFA by using its column, flame ionization detector and career gas. The dimension of the column was 30 m x 0.25 mm x 0.25 µm where Helium (He) was used as career gas. The temperature of the column was gradually increased from 110^{o}C to 220^{o}C with a rate of 10^{o}C/min. pH of the sample was determined by using a glass pH probe (Knick Portamess, 911 pH, Germany) whereas Total Ammonia Nitrogen was analyzed calorimetrically at 690®nm with Merck spectrophotometer (NOVA 60). The produced biogas from each reactor was measured by using the online gas measurement system that was composed with a water bath of 41x26x 25 cm (27L) dimension which further was equipped with gas measuring devices and the data acquisition system. The water bath system works according to the principle of water displacement by which the released biogas from the reactors passes through the tubes to its bottom where gas measuring devices or cells are located. The cells then generate the digital pulse of any defined biogas flow which is sent to the data acquisition system that calculates and stores the biogas production. Gas samples were analyzed for both CO_2 and CH_4 content using gas chromatograph Perkin Elmer Clarus 500 equipped with a Thermal Conductivity Detector and a Turbomatrix 16 Headspace auto sampler as described by Møller et al. (Møller et al. 2004). Methane and carbon dioxide was isolated by a 12' x 1/8" Haysep Q 80/100 Column. The temperatures of the injection port, oven and detector were 110, 40 and 150^{o}C respectively. Helium (He) was used as a carrier gas with a flow rate of 30 ml/min.

Co-digestion of *Ulva lactuca* and cattle manure in lab-scale reactors

Two reactors R_1 and R_2 with the capacity of 5 liters each and 3.2 liter working volume were simultaneously run at 22 days HRT. Both the reactors were placed in thermophilic incubator where the temperature was constantly maintained at 50±3 ^{o}C. The reactors were intermittently stirred for 5 minutes in every 45 minutes at 60 rpm by the steel rod fed with an electric motor (Zheng, China, 12 V) mounted on the top of the reactor lid. The experiment was initiated by feeding both the reactors with 3060 grams of inoculum in addition with 140 grams of cattle manure. R_1 was treated as reference reactor and fed only with cattle manure throughout the entire experimental period. Reactor R_2, on the other hand, was the experimental reactor that was also fed solely with cattle manure until the stable biogas production was achieved. The reactors had run and incubated for a very long time before the current experiment and therefore had reached the stabilization after a short period of 10 days incubation. This paper did not include the data before stabilization and reported the start of the experiment from the moment *Ulva lactuca* was added. Table 1 shows the variable parameters used in the co-digestion experiment of *Ulva* with cattle manure. After stabilization, R_2 was co-digested with cattle manure and algae *Ulva lactuca* with a variable OLR (Organic Loading Rate) of 0.31gVSL^{-1}d^{-1} to 1.11gVSL^{-1}d^{-1}. The VS addition and hence OLR of *Ulva lactuca* in reactor R_2 was increased stepwise at three different concentrations. The OLR concentration of 0.31gVSL^{-1}d^{-1} at 11% VS of *Ulva* was introduced at day 0 and was continued until day 31. The loading was further increased to 0.69 gVSL^{-1}d^{-1} and continued between day 32 to day 58 at 24% VS of *Ulva*. In the final incubation period, the OLR was additionally increased to 1.11 gVSL^{-1}d^{-1} corresponding to a 37% VS of *Ulva* that lasted from the day 59 to day 80.

Co-digestion of *Laminaria digitata* and cattle manure in lab-scale reactors

Unlike the experiment with *Ulva*, the continuous experiment for algae *Laminaria digitata* was conducted with four reactors (R_1, R_3, R_4, R_5) duplicated in two different treatments i.e. mesophilic (35^{o}C) and thermophilic (50^{o}C), each at HRT of 22 days. Reference reactor R_1 at thermophilic treatment was common for both the digesters running with *Laminaria* and *Ulva,* whereas reactor R_4 was used as reference for *Laminaria* at mesophilic condition. Both of these

Table 1

Experimental parameters (average) governing the anaerobic digestion of all the reactors

	R_1 (Control)			R_2 (Ulva)			R_3 (Laminaria)			R_4 (Control)			R_5 (Laminaria)		
Days	0-31	32-58	59-80	0-31	32-58	59-80	0-31	32-58	59-80	0-31	32-58	59-80	0-31	32-58	59-80
Temperature (^oC)		50			50			50			35			35	
TS/VS cattle manure (%)	6.01±1.5/5.4±0.6														
TS/VS *Ulva lactuca (%)*	20.4±7/15.0±0.4														
TS/VS *Laminaria digitata (%)*	15.5±1.5/10.5±1.05														
Feeding type (VS)	100% CM			11% Ulva	24% Ulva	37% Ulva	15% Lam	24% Lam	41% Lam	100% CM			15% Lam	24% Lam	41% Lam
pH	8.08	8.05	8.3	7.98	7.98	8.08	8.13	7.97	8.3	7.85	7.8	7.9	7.82	7.73	8.02
tVFA (mg/L)	306.6	64.4	88.4	73.4	118.6	1662	431	349.5	162.6	90.6	51.17	72.2	202	106.1	185.7
TAN (g/L)	2.08	2.0	1.85	2.14	2.11	1.15	2.03	1.48	1.69	2.13	2.28	1.78	2.3	2.1	1.6
CH_4 composition (%)	57.6	58.6	61.1	60	56.2	46.0	56.17	56.7	56.95	62.6	59.5	63.6	60.2	58	56.4
total CH_4 yield (L/kgVS)	154.1	142.2	126.2	157.6	133.5	70.8	119.6	165.6	185.7	143.6	130.6	124.3	139.2	136	139
CH_4 yield (L/L/d)	0.38	0.35	0.29	0.434	0.39	0.21	0.33	0.46	0.52	0.37	0.32	0.29	0.38	0.38	0.4
Algae CH_4 yield (L/kgVS)				164.9	129.6	72.1	35.6	192.3	197.7				128.5	142.2	142.0
Total OLR (gVS/L/d)	2.5	2.5	2.3	2.8	2.9	3.0	2.8	2.8	2.9	2.5	2.5	2.3	2.8	2.8	2.9
Laminaria OLR (gVS/L/d)							0.42	0.68	1.2				0.42	0.67	1.17
Ulva OLR (gVS/L/d)				0.31	0.69	1.11									
Laminaria feeding (g/d)							12	20	35				12	20	35
Ulva feeding (g/d)				5.8	13	25									
Cattle manure feeding (g/d)		140		134.2	127	115	128	120	105		140		128	120	105

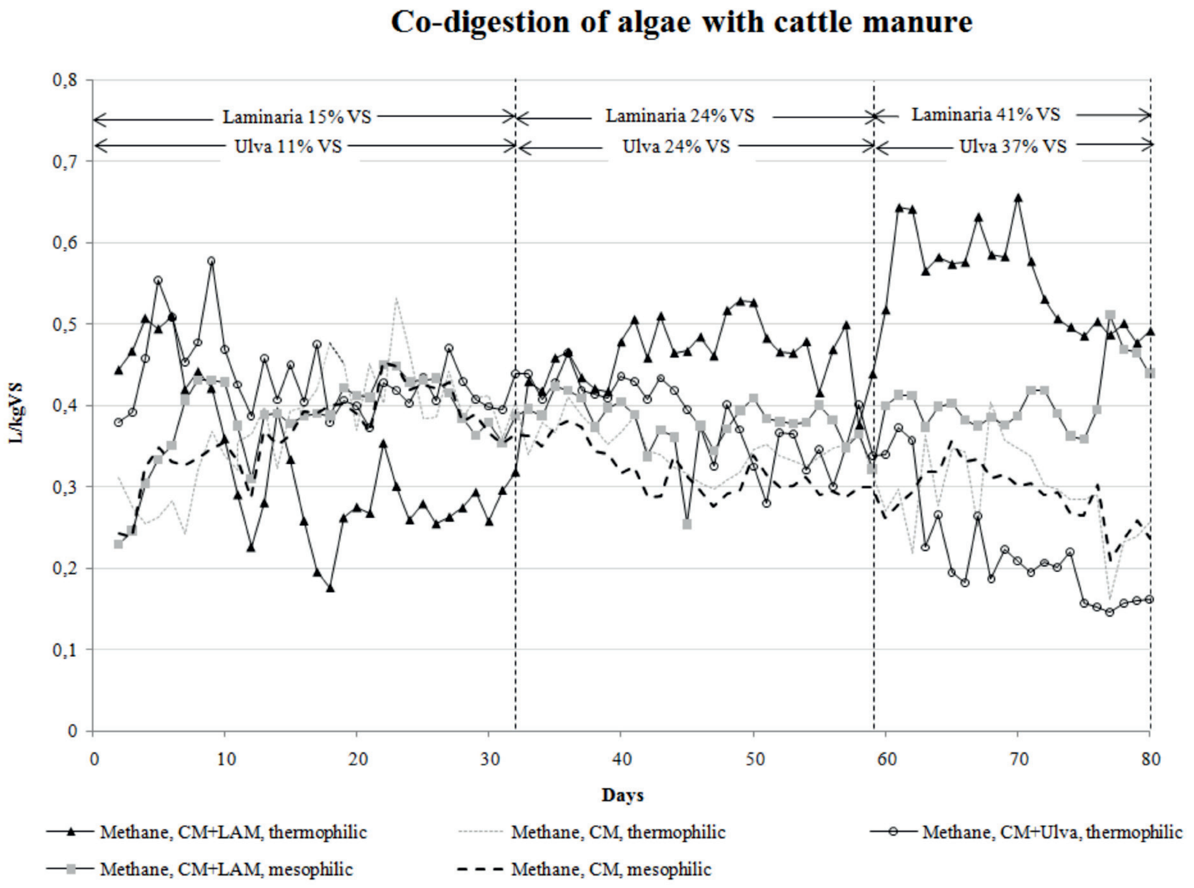
Source: made by the authors

reference reactors were fed exclusively with cattle manure throughout the entire experimental period, in contrast with the tested reactors which were fed only with cattle manure until the biogas production was stabilized. All the reactors (R_1 to R_5) were inoculated, stabilized and stirred in the same way, and reactors R_4 and R_5 were placed in the incubator that maintained temperature at 35±3 °C. R_1 and R_3, alternatively, were placed in the same thermophilic incubator (50±3°C) where R_2 (tested reactor for *Ulva lactuca*) was located. Co-digestion with *Laminaria digitata* and cattle manure for R_3 and R_5 were started after the stable biogas production was observed. Data during the stabilization period once again was not presented and the start of the experiment was determined by the start of the feeding of algae. Like the feeding of *Ulva*, the addition of *Laminaria* was also varied in three steps. In the first step (day 0-31), the R_3 and R_5 were supplemented with *Laminaria digitata* at 15% VS which corresponded to the OLR of 0.42 $gVSL^{-1}d^{-1}$ (table 1). The OLR was further augmented to 0.68 $gVSL^{-1}d^{-1}$ (table 1) with a corresponding 24%VS of *Laminaria digitata* from day 32 to day 58. The OLR was kept increasing and was fixed at 1.2 $gVSL^{-1}d^{-1}$ (table 1) between day 59 to day 80 at 41 % VS concentration of *Laminaria*.

Result and discussions

Co-digestion of *Ulva lactuca* and cattle manure in lab-scale reactors

The weight specific methane yield from the thermophilic co-digestion of *Ulva lactuca* with cattle manure for three different types of feeding is shown in figure 1. Generally, the methane yield from both R_1 and R_2 was gradually reduced throughout the experimental period. However, the difference of methane production between these two reactors was significantly expanded as the feeding concentration of *Ulva* in reactor R_2 was stepwise increased. For example, the control reactor (R_1) saw the three stage decrease in methane yield from 154.1 L/kgVS (between day 0-31) to 142.2 L/kgVS (day 32-58) and then to 126.2 L/kgVS (day 59-82) as the experiment proceeded. This perhaps can be attributed to the long storage of cattle manure contributing to the progressive decline in volatile solid content. Take R_2, on the other hand, at feeding volume of 11% *Ulva* (OLR of 0.31$gVSl^{-1}d^{-1}$), the average methane yield was 157.6 L/kgVS (0.43 L/L/day) between day 0 to day 31. Methane yield was first decreased to approximately 5% , from 157.6 L/kgVS to133.5 L/kgVS, when the feeding concentration of *Ulva* was raised to 24% (day32-58) and then to the highest 55%, from



Source: made by the authors

Figure 1. **Co-digestion of algae (*Laminaria digitata* and *Ulva lactuca*) with cattle manure**

133.5 L/kgVS to 70.8 L/kgVS, when the feeding was further augmented to 37% (day 59-80). The average methane yield and the value of other experimental parameters are tabulated in table 1. The high decrease in methane yield from R_2 was also reflected with a significant drop in methane composition (46%) and increase in total VFA (1662 mg/L) between day 59 to day 80. Clearly, the elevated feeding concentration of *Ulva* caused the instability in methanogenesis due to the overloading of VFA.

Co-digestion of *Laminaria digitata* and cattle manure in lab-scale reactors

Unlike R_2 (thermophilic reactor for *Ulva*), the methane yield from reactor R_3 (thermophilic reactor for *Laminaria*) was gradually increased as the feeding concentration of *Laminaria* was increased (figure 1). The methane yield from the reactor R_3 at feeding concentration of 15% *Laminaria* (0.42 $gVSl^{-1}d^{-1}$) was 119.6 L/kgVS which rose approximately 38% to 165.6 L/kgVS at *Laminaria* concentration of 24% (0.68 $gVSl^{-1}d^{-1}$) and approximately 55% to 185.7 L/kgVS (1.2 $gVSl^{-1}d^{-1}$) at the *Laminaria* concentration of 40% (of total feeding). This is in contrast with the reactor R_5 (mesophilic reactor for *Laminaria*) from which the methane yield was rather stable (average 138.06 L/kgVS) despite it was fed with similar variable *Laminaria* concentration for R_3. The mesophilic reference reactor R_4, on the other hand, followed the similar pattern (explained in previous section) of methane drop (from 143.6 to 130.6 and then to 124.3) like R_1 (thermophilic reference reactor) from the beginning till the end of the experiment. The higher average methane yield from the thermophilic *Laminaria* reactor (R_3) over the mesophilic *Laminaria* reactor (R_5) indicated the better methanogenesis and the adaptation of bacteria as an effect of higher temperature.

Conclusions

This study investigated the feasibility of methane production from the two algae species, *Ulva lactuca* and *Laminaria digitata.* The results from the co-digestion experiment of *Laminaria* with cattle manure at two different temperature conditions demonstrated that the gain in methane yield at thermophilic treatment is significantly higher than that from the mesophilic treatment as an effect of change in feeding. The deviation in methane yield from the sole temperature treatment of *Ulva* was also significantly large, but the trend is continuously downward as the feeding concentration was gradually increased. This work is yet to investigate the seasonal availability of algae based on which together with the findings so far, the choice of the type of algae for co-digestion with cattle manure can be determined.

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BIOMASS AS THE MAIN SOURCE OF RENEWABLE ENERGY IN POLAND

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Abstract
EU member states are obliged to introduce measures in order to meet objectives regarding minimum share of energy from renewable sources in gross energy use, as prescribed in Directive 2009/28/EC of the European Parliament and of the Council adopted on 23rd of April 2009. The present paper contains an overview of main aspects of renewable energy production in Poland with specific perspective of agriculture interests. Starting with a summarizing analysis of shares of renewable energy in total domestic energy production and consumption, structure of renewable sources used for energy production is given and analyzed. Specific attention is given to main source of renewable energy in Poland – solid biomass along with its historical and present quantification in the context of production methods used. Based on this, conclusions are drawn for perspective of meeting domestic target shares of renewable energy in total energy use by year 2020.
Key words: renewable energy, bioenergy, solid biomass, Poland.

Introduction

Directive 2009/28/EC of the European Parliament and of the Council on the promotion of the use of energy from renewable sources, adopted on 23rd of April 2009, sets a number of tasks for the EU member states. The main task is focused on compulsory national general objectives in relation to total share of energy from renewable sources in gross end use of energy. General objectives set by the directive in scope of share of energy from renewable sources in gross end use of energy in 2020 for respective EU member states are given in Table 1. For comparison, share of renewable energy sources in gross end use is also shown for 2005.

Data from 2005 indicate large variation of renewable energy sources among EU member states. Member states with largest share of energy from renewable sources include Finland, Latvia and,Sweden – these countries in 2005 had twice the share of renewable sources (28.5, 34.9 and 39.8% respectively) of the 2020 target shares of countries like Germany, Poland and Great Britain (18.0, 15.0, 15.0%). The objective for Poland is to increase the share of renewable energy in the general energy use up to 15% by 2020. The framework for development of renewable energetics in Polish energy policy was elaborated even before accession to the EU in the form of a governmental document titled "Strategy for development of renewable energetics", adopted by Polish Parliament on the 23rd of August 2001. The document was refined on the 10th of November 2009 by the Government in "Energy policy for Poland to 2030". It has been stated there, that the strategic objective of domestic energy policy is an increment of use of renewable energy resources, so renewable energy would make up a share of 15% of total gross energy use by 2020. Moreover, general objectives were adopted in scope of share of electrical energy from renewable resources in total electrical energy production and share of biofuels in fuel use in general. According to these assumptions, share of electrical energy obtained from renewable sources in the general use of energy in Poland should reach 7.5% in 2010; 10.4% in 2012; 10.9% in 2013; 11.4% in 2014 and 12.9% in 2017. Share of liquid biofuels should account for 10.0% in 2020, and in the preceding years, according to the 2011 regulation of the Government, under the act of 25th of August 2006 on biocomponents and liquid biofuels it should make respectively:

6.20 %	in 2011	7.55 %	in 2014
6.65 %	in 2012	8.00 %	in 2015
7.10 %	in 2013	8.45 %	in 2016

It should be noted, that the adopted assumptions for years 2008, 2009 and 2010 of respectively 3.45%; 4.60% and 5.75% have all been achieved. Contribution of biocomponents in fuels used in transport in 2008, 2009 and 2010 was respectively 3.66%; 4.63% and 6.46%.

Obtaining of primary energy in Poland, including production of energy from renewable sources in years 2001-2010, is shown in Table 2. Production of primary energy in Poland in that time decreased, which along with increasing GNP indicates larger effectiveness of energy use by Polish economy. With decreasing production of energy in general, production of energy from renewable sources was increasing systematically. It increased from 4.1 share to 6.8 Mtoe in years 2001-2010, while share of energy from renewable sources in primary energy in general increased from 5.1% to 10.2%.

Energy from renewable sources in Poland is produced mainly from solid biomass (Table 3). Despite production of energy from biomass is increasing, the

Table 1

Share of energy from renewable sources in gross end use of energy in EU member states in 2005 and the set target share for 2020

EU member states	Share of energy from renewable sources in gross end use of energy (%)		EU member states	Share of energy from renewable sources in gross end use of energy (%)	
	2005	2020		2005	2020
Belgium	2.2	13.0	Luxembourg	0.9	11.0
Bulgaria	9.4	16.0	Hungary	4.3	13.0
Czech	6.1	13.0	Malta	0.0	10.0
Denmark	17.0	30.0	The	2.4	14.0
Germany	5.8	18.0	Netherlands	23.3	34.0
Estonia	18.0	25.0	Austria	7.2	15.0
Ireland	3.1	16.0	Poland	20.5	31.0
Greece	6.9	18.0	Portugal	17.8	24.0
Spain	8.7	20.0	Romania	16.0	25.0
France	10.3	23.0	Slovenia	6.7	14.0
Italy	5.2	17.0	Slovakia	28.5	38.0
Cyprus	2.9	13.0	Finland	39.8	49.0
Latvia	34.9	42.0	Sweden	1.3	15.0
Lithuania	15.0	23.0	Great Britain		

Source: GUS, 2011a

Table 2

Obtained primary energy (including energy from renewable sources) in Poland in years 2001-2010

Specification	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Obtained primary energy in total (Mtoe)	80.2	80.0	79.9	78.7	78.4	77.7	72.6	71.3	67.3	67.2
of which energy from renewable sources (Mtoe)	4.1	4.1	4.1	4.3	4.5	4.8	4.9	5.4	6.0	6.8
Share of renewable sources energy in total primary (%)	5.1	5.2	5.2	5.5	5.8	6.1	6.7	7.6	9.0	10.2

Source: GUS, 2011a

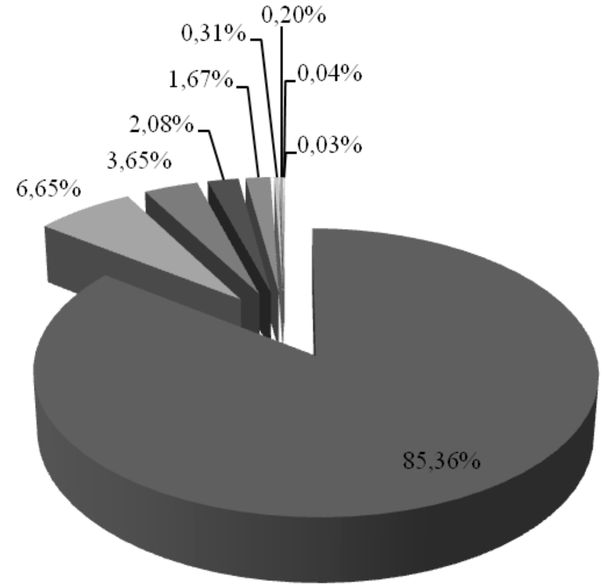
Table 3

Sources of renewable energy in Poland in years 2005-2009

Specification	(Mtoe)					(%)				
	2005	2006	2007	2008	2009	2005	2006	2007	2008	2009
Solid biomass	4.12	4.36	4.49	4.73	5.17	91.6	90.8	91.6	87.7	86.1
Water power	0.19	0.18	0.19	0.18	0.20	4.2	3.7	3.9	3.4	3.4
Wind power	0.01	0.02	0.04	0.07	0.09	0.3	0.5	0.9	1.3	1.5
Biogas	0.05	0.06	0.06	0.10	0.10	1.2	1.3	1.3	1.8	1.6
Biofuels	0.12	0.17	0.10	0.30	0.42	2.6	3.5	2.1	5.5	7.1
Geothermal energy	0.01	0.01	0.01	0.01	0.01	0.2	0.3	0.2	0.2	0.2

Source: GUS, 2011a

share of this type of energy source in total renewable energy production dropped from 91.6% in 2005 down to 85.6% in 2010. This resulted in larger increments of shares of energy obtained from biofuels, as well as larger shares of wind energy. Moreover, there is also a significant contribution of water power in sources of renewable energy. Renewable energy sources listed in Table 3 are the primary renewable energy media in Poland. Apart from them, in the recent years, renewable energy is also obtained from sources like heat pumps, municipal waste and solar radiation. However, share of these media is much less significant.



Source: GUS, 2011a

Figure 1. **Share of renewable energy sources in total production of renewable energy in Poland in 2010**

Table 4

Share of electrical energy obtained from renewable sources in gross domestic use of electrical energy in years 2005-2010

Specification	2005	2006	2007	2008	2009	2010
Use of electrical energy in Poland (TWh)	145.7	150.8	154.0	153.4	149.5	156.1
Production of electrical energy from renewable sources (TWh)	3.761	4.222	5.230	6.493	8.604	10.895
Share of electrical energy obtained from renewable energy sources (%)	2.58	2.80	3.40	4.23	5.76	6.98

Source: Ministry of Economy, 2010

The structure of renewable energy media contribution in 2010 is shown in Fig. 1. The largest portion falls to biomass energy with 85.36% of renewable energy in 2010 being obtained from this medium. Following renewable media and their share in total renewable energy output in 2010 are as follows: liquid biofuels – 6.65%, water – 3.65%, wind – 2.08%, biogas – 1.67%, heat pumps – 0.31%, geothermal energy – 0.20%, municipal waste – 0.04%, solar radiation – 0.03%.

Production and use of electrical energy in Poland have been systematically growing. In the recent years, use of electrical energy increased has by 7.14% from 145.7 TWh in 2005 up to 156.1 TWh in 2010 (Ministry of Economy, 2010). Production of electrical energy from renewable sources during that period increased from 3.761 TWh up to 10.895 TWh, that is almost threefold, while share of renewable electrical energy in total renewable energy went up from 2.58% to 6.98%, which is almost the assumed target share of 7.5% for 2010. In 2010, the largest share of renewable electrical energy was that of solid biomass (53.1%). Dynamic development of wind power has nevertheless been noticed in this context as well.

Production of electrical energy from wind power increased more than thirteen times during 2005-2010, electrical energy obtained from solid biomass went up four times and energy obtained from biogas by three times. Lowest increase of 34.0% in share was that of water power energy. Up to 2006, water was the largest source in Poland, and from 2007 up to now – second largest source of renewable source of electrical energy (Table 5).

Biomass remains the main renewable source of energy in Poland. In 2010, share of biomass in total renewable energy production accounted for 85.36% and 53.1% for electrical energy. Up to now, main source of biomass energy is co-incineration of forest biomass with other fuels. Estimated share of this biomass source in the general biomass use for energy purposes accounted for 47.8% in 2010. Supply of forest biomass for energy production in limited. In face of significant deficit of

Table 5

Size and structure of renewable sources for electrical energy production in Poland in 2005-2010

Specification	(GWh)						(%)					
	2005	2006	2007	2008	2009	2010	2005	2006	2007	2008	2009	2010
Solid biomass	1345	1818	2343	3313	4 888	5 788	35.8	43.1	44.8	51.0	56.8	53.1
Water power	2176	2030	2 253	2 153	2 376	2 922	57.9	48.1	43.1	33.2	27.6	26.8
Wind power	135	257	472	806	1 045	1 822	3.6	6.1	9.0	12.4	12.1	16.7
Biogas	105	117	162	221	295	363	2.8	2.8	3.1	3.4	3.4	3.3

Source: Ministry of Economy, 2010

Table 6

Wood production in Poland in 2010

Specification	Total wood obtained (m^3)	of which firewood (m^3)
Total wood production	35 467 471	4 124 415
Large softwood timber	25579421	1364383
Large hardwood timber	7988866	1352191
Small sized softwood and hardwood	1 899 123	1 407 841

Source: GUS, 2011b

Table 7

Agricultural land area (thous. ha)

Specification	1990	2005	2010	2020 estimate
Total area of agricultural land	18720	15906	15534	15600
of which: arable land	14388	12222	10931	11800
orchards	272	297	363	350
meadows	2475	2529	2635	2380
pastures	1585	858	619	700
others	-	-	986	370

Source: GUS, 2011b

wood for various branches of economy in Poland (e.g. the furniture industry) and increasing wood prices along with necessity for maintaining of a balanced and multi-functional forest policy, energy purposes cannot consume quality wood. Therefore when estimating forest wood supply for energy production, only stock like firewood (both softwood and hardwood) and small sized firewood should be considered – and in 2010 this accounted for 11.6% of wood obtained in Poland (Table 6).

Poland is considered in the EU as a country of large potential for biomass production for energy purposes with the use of arable land, which allows to estimate its area per capita in 0.41 ha (GUS, 2011b). In the past 20 years (1990-2010) arable area decreased by over 3.0 mln ha (Table 7). This drop resulted from transferring of arable land for non-agriculture purposes, including afforestation of roughly 250 thous. ha, as well as from other changes in its classification. Low yield levels of most crops allow relatively easy enhancement of per-hectare productivity and obtaining of production volume necessary for food and feed purposes, using smaller arable land area. In this situation, land "freed" from food and feed production could be used for energy biomass production. Estimates and analysis results in this scope show, that arable area, which could be transferred for energy biomass production in Poland may account even for 4.0 mln ha (Wisental, 2006; Kuś et al., 2009).

In Poland it is estimated that by 2020 the demand for solid biomass energy will be around 10 million tonnes of dry matter. Assuming that forestry can provide around 2 million tons of waste wood and that agriculture would yield about 3 million tons of straw,

Table 8

Crop areas for various crops for energetic purposes (ha)

Specification	2009	2010	Specification	2009	2010
Perennial plants	**6786.7**	**11022.2**	**Annual plants**	**22411.3**	**14643.5**
Salix viminalis	5140.7	8534.4	Cereals	5695.1	3448.2
Rosa multiflora	3.5	5.5	Sugar beets	114.4	4540.2
Sida hermaphrodita	27.6	80.0	Winter and spring rape	16331.2	6285.5
Miscanthus giganteus	1157.6	1929.9	Soybean	17.3	140.5
Helianthus tuberosus	58.6	38.1	Others	253.3	229.1
Reynoutria sachalinensis	0.0	1.0			
Phalaris arundinacea	236.9	215.0			
Others	161.9	218.4			

Source: GUS, 2011b

the remaining 5 million tonnes of biomass would be sourced from energy crops such as *Salix viminalis, Miscanthus giganteus* and other species of perennial grasses like *Sida hermaphrodita* (Kuś and Faber, 2007). With an average yield of around 10 tonnes of dry matter per 1 ha, the area for energy crops will be about 500 thousand hectares. National Indicative Target adopted by the Ministry of Economic Affairs aims to increase the share of bio-components in liquid fuels from 5.76% in 2010 to 10% in 2020. For the assumed consumption of diesel and the required biodiesel additive, it will be necessary to process nearly 2 million tons of rapeseed. With a yield of about 3.2 t/ha for rapeseed, about 550 thousand hectares of areas will have to be dedicated to this oilseed. A similar area of about 600 thousand hectares must be used to acquire grains, potatoes, sugar beet, etc. required for bioethanol production (Kuś and Faber, 2007). A dynamic development of biogas plants on farms is also observed in Poland, and their target number may reach 2 thousand facilities. Assuming that half of the substrates would be derived from waste materials and the other half from biomass of field crops (150-200 ha corn or others species) the necessary area for their cultivation would have to be around 300-400 thousand hectares. Restructuring and intensification of production in Polish agriculture and an on-going growth of crop as well as livestock production, allows allocation of around 2 million ha out of 16 mln ha of total crop areas for energy purposes. The remaining crop areas would still more than suffice to meet up-to-date goals pursued by agriculture sector in Poland.

In the recent years Poland has witnessed crop production of both perennials and annuals for energetic purposes. Perennials have been grown for combustible biomass and annuals for liquid biofuel production and biogas production (in case of maize). Crop areas for energetic perennials and annuals are shown in Table 8. Comparison of estimated demand for biomass production by cropping energy plants with actual crop area indicates that energy crop agriculture is still in the early stage of development. Area of the highest energy efficiency crop like *Salix viminalis*, *Miscanthus giganteus* is still very small and in 2010 it accounted for 8534.37 and 1929.93 ha respectively. Both crops were dominating in the group of energetic perennials. It should be stressed that in 2010 crop area for perennials increased by 4236.5 ha, that is by 62.4%, compared to 2009. On the other hand, crop area for energetic annuals decreased to 14643.48 ha in 2010, compared to 22411.28 ha in 2009. The main reason behind this is lower production of rapeseed biodiesel.

Conclusions

Development of renewable energy in Poland, similarly to other EU member-states, is of significance in context of fundamental goals of Polish energy policies. Increasing of energy production from renewable sources would allow broader independence from imported energy, as well as would yield positive ecological effects.

Main goals for the development of renewable energy sources in Poland encompass increasing of share of renewable energy in total energy use by no less than 15%, and increasing of biofuel share in the transportation fuels market by 10% in 2020 and further increments of these shares in following years.

Increasing of diversification of means to obtaining renewable energy sources and establishing of optimal conditions for development of distributed energetics based on locally available resources should be considered the two main, immediate tasks. In case of biomass as source of renewable energy, primary concern should be protection of forest resources from overexploitation, as well as introduction of larger, sustainable involvement of agricultural areas for this purpose. It is indispensable to intensify production of biomass for energy purposes on agricultural areas, both through cropping of perennials and annuals, respectively for obtaining of biomass for combustion and for liquid fuel and biogas production. This should result in competition between energy production and agriculture, as well as promote ecological biodiversity. Large share of agricultural land in total area of Poland, together with intensification of production in Polish agriculture, should allow to assign part of agricultural areas for energy crops.

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SMALL CHP PLANTS IN LATVIA: REALITY AND POSSIBILITIES

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Abstract
The paper observes different steps which can be made to stimulate the development of small cogeneration using renewable fuels in Latvia.
Combined heat-and-power (CHP) plants generate electricity together with the heat at high efficiencies (depending on technology and type of fuel) and therefore help to save fuel, cut greenhouse gas emissions and reduce electricity costs. According to the Latvian Energy Policies (for the period of 2007-2016yy), one of its main aims is to increase the effective usage of renewable sources of energy and producing of energy in cogeneration process, including the stimulation of small cogeneration.
Today in Latvia there are 12 CHP plants with electrical capacity less than 0.2 MW and 39 CHP plants with electrical capacity 0.2 – 5 MW. During the last two years, the amount of small CHP plants has increased from 36 to 51. Only 5 of existing CHP plants use renewable fuels, the others use natural gas.
The conditions for CHP producers, apart for small-scale CHP, have been difficult over the last few years. The development of small-scale CHP projects is hindered by the lack of experience with new technologies, as for example wood gasification or micro turbines, together with high interconnection. During last time, the procedure of taking business loans became more difficult, as well.
Latvia supports cogeneration by means of feed-in tariffs. The tariffs depend on the installed electricity capacity of the CHP units. The main weak point of the policy measures can be identified as discrimination between different cogeneration plants, and particularly of small and micro systems, because at least 75 % of the heat produced has to be supplied to the centralized district heating, hence the policy does not support industrial or auto-use of cogenerated heat. It is necessary to simplify technical and administrative procedure for newly created CHP plants, especially for the ones with capacity less than 4 MW and the ones using renewable fuel.
In 2011 a training program 'Sustainable heating system with Renewable energy resource' was started in Latvia. The sustainable energy community model (SEC) modified for Latvian circumstances is used in the project. Firstly, there was analyzed the energy efficiency of different Latvian regions to find out the most prospective field for applying the SEC method. The farther steps are to analyze accessible resources (including renewable) for a definite region, and then to create and realize the plan of energy development. While implementing this kind of programs it is possible to stimulate the farther development of cogeneration in Latvia, including small capacity CHP plants, using local renewable fuels.
Key words: cogeneration, local level energy policies, main drivers and main barriers for growth of renewable energy.

Introduction

Nowadays, the world's increasing interest is observed in two aspects of energy problems – energy dependence and climate change. Many investigations are being made on alternative energy sources and new technologies. To achieve the aims of European Union (EU) energy and climate policy till 2013-2020, the European countries have to concentrate on increasing both energy efficiency and renewable fuels usage.

The possible principles of Energy Policy for Europe were elaborated at the Commission's green paper A European Strategy for Sustainable, Competitive and Secure Energy in 2006. As a result of the decision to develop a common energy policy, the first proposals, Energy for a Changing World were published by the European Comission, following a consultation process in 2007. The European Commission has proposed in its Renewable Energy Roadmap 21 a binding target of increasing the level of renewable energy in the EU's overall mix to 20% by 2020. The targets for the member states are calculated using a formula: flat rate 5.75% (one for all EU countries) + extra % (according to GDP).

According to the European Climate and Energy package, Latvia, as a European Union Member state, has to increase the renewable energy as a part of gross final energy consumption from 35% in 2005 to 42% in 2020 (Odiņeca T., 2009) to increase energy efficiency and to reduce the greenhouse gas emissions by 2020. The combination of renewable energy sources (RES) and combined heat and power (CHP) is a key approach to reach the ambitious EU climate protection targets. The aim of the paper is to observe different steps which can be made to stimulate the development of small cogeneration using renewable fuels in Latvia.

Existing situation with CHP plants in Latvia

Latvian energy policy towards CHP plants

Reaching the long-term goals of Latvia's energy sector is a complex process that involves finalizing a long-term strategy, defining and justifying feasible goals and tasks, as well as establishing concrete political, legal and institutional frameworks and tools (Sprūds A., 2010; Latvijas Republikas Ekonomikas ministrija, 2006).

The key strategic document for the energy sector is The Principles of Energy Sector Development 2007-2016, adopted in 2006. This document defines the fundamental principles of the Latvian government policy, as well as long-term goals and a course of action in the energy sector. The importance of the energy sector in the context of overall sustainable development is acknowledged: 'The sufficiency of energy supply in the country is the issue of economic development, the quality of life and state security. The goal of the energy sector development is to ensure balanced, safe, sustainable high quality supply of energy for the economy and country's residents.' The goals spelled in the document are identical to the 'three whales' of the energy sector as defined by the EU, namely: 1) secure supply, 2) encouraged competition and competitiveness, and 3) use of renewable resources.

To put the Principles of Energy Sector Development 2007-2016 into practice, there were mentioned, among other, these plans of action:

- until 2016 to use the potential of cogeneration with common heating load about 300 MW_{th} in Latvian big cities (including Riga), and 100 MW_{th} in other Latvian cities;
- to stimulate the development of CHP plants and energy producing of renewable sources of energy, using the EU Fund's special purpose grants for investments;
- to increase the usage of local renewable primary resources from 65 PJ at the moment to 82 PJ in 2016 (36-37% of local resources in Latvian primary energy resources structure);
- until 2016 to increase the energy efficiency of heat production facilities from 68% to 80-90%.

Using of cogeneration technology is considered appropriate to Latvia's situation: Latvia has a characteristic centralized power supply system, which means inhabited areas have sufficiently high heat loads to accommodate installation of an efficient cogeneration facility. A cogeneration source is close to the heat load, i.e. the energy consumer, who is consuming power at the same time. This means that cogeneration technology has all the advantages of placing an energy source next to the consumer, such as reduced power management and distribution leakage, and increased power supply stability.

A wide variety of fuels can be used in CHP systems, including natural gas, diesel fuel, petrol, biofuels, coal, municipal waste. CHP plants operate at total energy efficiencies of 75-95 %, which means that almost all of the fuel is put to productive use (Flin D., 2010). Because less fuel is used, obvious benefits are received:

- reduced fuel costs;
- reduced fuel supply needs, bringing about a reduction in the logistical needs to transport and store the fuel;
- reduction in emission levels;
- fewer pollutants passing through the engine or turbine, resulting in a reduction in wear.

Review of existing CHP plants in Latvia

Data of the Central Statistical Bureau show that in 2010 in the Republic of Latvia there were 71 active combined heat and power (CHP) plant with total electrical capacity 947.5 megawatts (MW) (Suzdaļenko V. 2011). These CHP plants produced 3050 gigawatt hours (GWh) of electricity and 4673 GWh of heat energy, and it is 58.7% of total volume of heat produced.

There are two types of CHP plants:

- public CHP plants, primary activity of which is generation of heat energy;
- autoproducer CHP plants are generating heat for their own consumption and technological use and partly for sale.

Out of 71 CHP plants, in 2010 there were active 56 public cogeneration plants with installed electrical capacity 932.8 MW, it is 98.4% of total installed capacity of CHP plants, and 15 were autoproducer CHP plants with installed electrical capacity 14.7 MW.

In comparison with 2009, electrical power of cogeneration plants has increased by 1.4%. CHP plants of Riga had the highest installed electrical capacity – 876.3 MW.

In 2010 for the production of heat energy and electricity, CHP plants mainly used natural gas (98.1%), as well as biogas, fuelwood, coal, residual (heavy) fuel oils and bio-diesel oil.

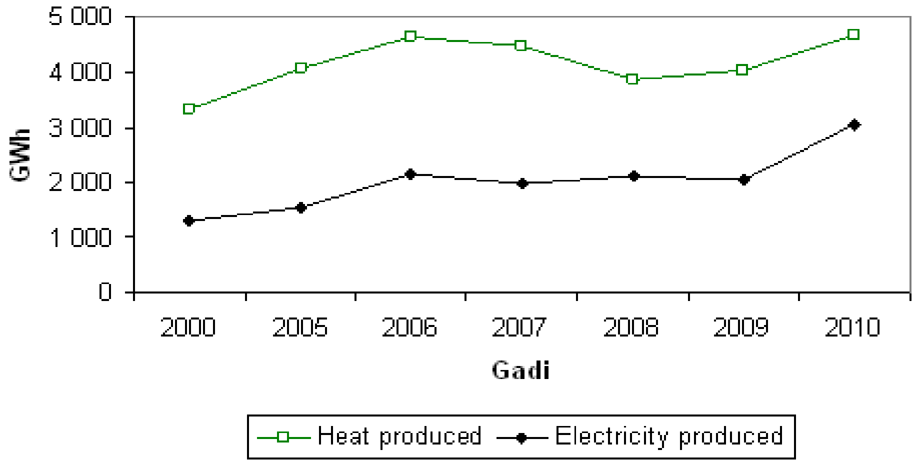
Out of 71 CHP plants, in 2010, 56 plants (both public and autoproducer) with total electric capacity 870 MW were active for more than 6 months, of which:

- 3 combined-cycle turbines with electrical capacity 803 MW;
- 1 gas turbine with heat utilisation;
- 48 internal combustion engines with electrical capacity 61 MW;
- 3 steam backpressure turbines with electrical capacity 4 MW;
- 1 condensing steam turbine.

Methods of support of CHP development

Documents regulating producing of co-generated energy

The most important energy-related legislative document is the Energy Law (2005), which regulates the use of and support for all renewable resources. The government has also adopted a series of regulations



Source: Suzdaļenko V., 2011

Figure 1. **Heat and electricity produced in CHP plants in 2000 to 2010 (GWh)**

Table 1

Number of public CHP plants and installed electrical capacity (MW) in 2010

	Number of public CHP plants	Installed electrical capacity, MW	Electricity produced, GWh	Heat energy produced, GWh
TOTAL	**56**	**932.8**	**2984.8**	**4603.4**
≤ 0.2 MW	8	1.3	7.2	20.2
0.2 < P ≤ 0.5 MW	14	5.7	23.5	99.1
0.5 < P ≤ 1 MW	9	6.2	23.9	197.6
1 < P ≤ 5 MW	21	54.3	323.3	867.4
5 < P ≤ 20 MW	1	11.8	35.7	36.9
> 20 MW	3	853.5	2571.2	3382.2

Source: Suzdaļenko V., 2011

for CHP plants; the most notable among them is the Regulation No. 221 ‘The Regulation of electrical energy production and forming of prices while producing electrical energy in CHP’ (10 March, 2009) (Ministru kabinets, 2009).

Of many possible variants of support schemes for CHP using renewable energy sources (including green certificates, tax exemptions or reductions, tax refunds, premium payments), in Latvia there are used the following: feed-in-tariffs, obligate buying of co-generated electrical power, EU earmarked subsidies for the development of CHP plants using RES.

In the latest amendment to Regulation No.221, a few changes referring to small capacity CHP plants were brought in (Ministru kabinets, 2009; Ministru kabinets, 2005). In the period from 2007 to 2010, the number of CHP plants with electrical capacity 0.2 – 5 MW significantly increased.

The feed-in-tariffs, defined by Regulation No.221, depend on the installed electricity capacity of the CHP units. The main weak point of the policy measures can be identified as discrimination between different cogeneration plants, and particularly of small and micro systems, because at least 75 % of the heat produced has to be supplied to the centralized district heating. Thereby, the policy does not support industrial or individual-use of cogeneration. The natural gas tariff is used as an element of the pricing formula for electricity produced at biogas and biomass power stations, which should be abolished.

Applying a Sustainable Energy Community model for development of CHP

In 2011 a training program ‘Sustainable heating system with renewable energy resource’ was started in Latvia. The modified sustainable energy community model (SEC) is used in the project.

The Sustainable Energy Community model begins by establishing a clearly defined geographic area called the Sustainable Energy Zone (SEZ). The SEZ establishes sustainable energy targets that are measured and monitored and creates a focal point for partners, projects and proposals to integrate in a structured way. This allows new technologies and techniques to be tried and tested in an incubator or living laboratory environment.

A Sustainable Energy Community is the integration and collaborative action in the wider community

Table 2

Number of public CHP plants and installed electrical capacity (MW) in 2007 and 2010

	2007		2010	
	Number of public CHP plants	Installed electrical capacity, MW	Number of public CHP plants	Installed electrical capacity, MW
TOTAL	**20**	**586,2**	**48**	**931,5**
0.2 < P[1] ≤ 0.5 MW	3	0,637	14	5,7
0.5 < P ≤ 1 MW	0	0	9	6,2
1 < P ≤ 5 MW	9	18,95	21	54,3
5 < P ≤ 20 MW	5	47	1	11,8
> 20 MW	3	519,6	3	853,5

Source: Suzdaļenko V., 2011

(e.g. town or region) to expand and replicate ideas tested in the SEZ. This is delivered through structured engagement with the wider public, private and community sectors to identify synergies and supporting initiatives to influence positive changes in behaviour and policy. An SEC is a community in which everyone works together to adopt a more sustainable pattern of energy supply and use (SEC Program, 2007).

Applying the SEC model modified for Latvian circumstances, firstly, there was analyzed the energy efficiency of different Latvian regions to find out the most prospective field for using the SEC method. Then it is starting the process of energy development planning, which includes 8 steps:

- forming the total vision of region (local energy resources, economy, demography, etc);
- defining of motive power in a region;
- defining of base line of development;
- working out the scenarios of development;
- formulating the strategy;
- formulating the plan of actions;
- monitoring and estimating the progress;
- adapting the new information for the planning process.

While implementing this kind of programs, it is possible to stimulate the farther development of cogeneration in different Latvian regions, using local energy sources.

Usage of renewable energy sources for CHP plants

As it is said before, today for the production of energy CHP plants mainly use natural gas (98.1%). It is explained by the fact that using natural gas as a fuel, it is possible to apply highly effective (with high α-ratio) CHP technologies. One of Latvia's advantages, which also serve as a kind of short-term guarantee of continual supply, is its underground gas storage facilities. The amount of active gas in the currently functional Incukalns underground storage may reach 2.3 billion cubic meters, and there are plans to increase this amount to 3.2 billion cubic meters. The expansion of these storage facilities may bring about several significant advantages, such as strategic reserves, economic benefits and improvement of regional energy supply. Nevertheless, it may also boost local energy and production companies' inclination to use imported gas instead of exploring sustainable local options by means of increasing energy efficiency and using renewable energy sources.

Considering the aforementioned local and regional challenges, as well as the EU commitments, it would make sense for Latvia to utilize the potential of local renewable sources, the largest of which is wood. The economic potential of wood is estimated around 45.5 – 82 PJ a year, which constitutes considerable part of the country's total energy consumption.

Wood gasification technology (a thermo dynamical process that converts wood to a gaseous fuel) used in cogeneration process is more effective than common combustion of wood, because generated gas can be a fuel for such effective CHP technologies as gas turbines, gas-steam turbines and internal combustion sets. Wood gasification is less dangerous for enviroment comparing with common combustion, because during gasification process less emissions go to the atmosphere. Usage of wood fuels not only helps to increase the part of renewable energy in gross final energy consumption, but also gives an opportunity to get more independence from importing of fossil fuel resources. Besides, the gas distribution system in Latvia does not cover large territories, including the territories with big forest density. The advantage of the use of biomass in cogeneration is self-evident, as it allows high efficiency combined with an increase of renewables' share. While CHP equipment fuelled by RES seems to be the first choice from the standpoint of energy efficiency and technical availability, it is not yet widely spread and implemented.

If gas is used in an internal combustion engine for the production of electrical energy, it demands a gasifier and gas of special quality. The world's experience of exploitation of this kind of systems shows, that they are sensitive towards the changes of fuel parameters, changes of the load of equipment, quality of service, and environmental conditions. Necessity of cleaning, cooling and mixing of gas makes the technology rather difficult and expensive (Odiņeca T., 2009).

Today, there are two CHP plants where wood gasification is applied: SIA 'Kņavas granulas' in Vilani (electrical capacity 500 kW and thermal capacity 800 kW) is fuelled by wood granules (the drying of fuel is not necessary), and SIA 'Zaļās enerģijas aģentūra' in Dagda (works since 2010; electrical capacity 500 kW and thermal capacity 800 kW; an internal combustion engine installed) is fuelled by dry woodblocks and dried coarse fraction woodchips (Ozoliņa L., 2011).

CHP goes 'green'

Access to information is a problem in the public energy supply system of Latvia. The frequently used argument goes that energy consumers do not understand this complex issue and therefore no information needs to be released to the general public, except for the regulated energy tariffs. Yet sustainable development is unfathomable without the awareness and understanding of energy producers' and energy consumers' actions and their mutual interconnectivity. Latvia has not made sure there is a system allowing energy consumers to obtain information about the sources of the energy they consume, about the security of energy supply, price predictability and alternative energy options. The lack of such a system hinders the development of a clear policy of the energy sector and impedes investment.

Since 2010 Latvia participates in the EU project 'CHP goes Green' (CHP Goes Grees. Project, 2011). The target for the selected model cities (Berlin, Frankfurt/ Main, Hannover, Graz, Prague, Riga, Lyon and Paris) involved in the project is to promote and install 'Green CHP' and the respective technical solutions. All players in the decision-making chain are addressed by CHP goes Green: public and private buildings owners, local key politicians, municipalities, planning engineers, installers, energy companies and industry.

The benefits to the target groups are manifold such as:

- solution-oriented contributions to reaching local energy goals;
- information in terms of innovations, competition and best choices;
- the provision of contact with target groups;
- considerations in terms of feasibility of CHP solutions.

The following major outputs related to the goal will be realized:

- analysis of the regional legal and economic framework and its impact on the regional market exemplarily for the model region;
- derivation of action and implementation plans of good practice specific for the model region;
- the public campaigns addressing policy and decision makers, building owners and youngsters as future decision makers;
- target-group specific promotion of best practices for RES-fueled CHP approaching different groups of building owners, planners and installers;
- initiating new RES-CHP applications;
- training of above mentioned decision makers with regard to technical, ecological and economic issues to support the practical implementation of RES-fueled CHP.

Conclusions

Usage of SEC methodology modified for Latvian circumstances is appropriate for development of cogeneration in definite Latvian districts.

Further market penetration of higher share of cogeneration fuelled by renewables requires removing barriers from the legislative and administrative framework, requires planning and cooperation, capacitating of technical decision makers and general awareness-raising and trust-building among potential promoters, multipliers and users. Moreover, it is a question of cost if alternatives are considered. It is worth investing in developing the new effective technologies used in cogeneration (wood gasification).

It is necessary to simplify the technical and administrative procedure for newly created CHP plants, especially for the ones with small capacity and the ones using renewable fuel. The support mechanisms for using of cogeneration have to apply not only to businesses, but also to individuals. It also can be recommended to abolish the natural gas tariff as an element of the pricing formula for electricity produced at CHP plants using renewables.

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SPECIFIED EVALUATION OF MANURE RESOURCES FOR PRODUCTION OF BIOGAS IN PLANNING REGION LATGALE

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Abstract
Evaluation of manure production from different livestock is important for business planning in bioenergy sector. According to proposed legislation, share of animal sourced byproducts, including manure, can be limitative for application on state aid for new biogas plant building and for feed-in tariff calculation for purchase of electricity produced in biogas plants. For calculation purposes, livestock was divided into 11 different groups, and animals in every group have approximately same manure output per head in a year. Manure resources from dairy cow were calculated with consideration of average milk yield within every parish or municipality in Latgale planning region. Biogas potential obtainable from livestock manure was 11.2 million m^3, including 77.6% from cattle 17.4% from pigs, 4.5% from poultry and 0.5% from horses in planning region Latgale in 2011.
Key words: biomass waste, livestock manure, anaerobic digestion.

Introduction

Political strategy is aimed to enact the provisions of Directive 2009/28/EC in Latvia by development of production of renewable energy, including energy production from biomass. Renewable energy share in gross energy consumption should to increase from 32.5% in year 2005 up to 40% in year 2020. The development scenario anticipates that in the electricity sector the share of GFEC increases from 44.9% in 2005 to 59.8% in 2020, in the corresponding period in the heating and cooling sector the share increases from 42.7% to 53.4%, and in the transport sector the share increases from 0.9% to 10% (Ministry of Economics, 2011). Manure is the largest and cheapest resource for biogas production in planning region Latgale. Anaerobic treatment of manure reduces emissions of methane and other harmful substances into environment to great extent. Careful evaluation of manure resources for biogas production can contribute to estimation of digesters volume and capacity of cogeneration units. Specified evaluation of available resources is needed also for successful application for obtaining of EU and state's financial support for building of biogas cogeneration plant and for obtaining of financial support from potential investors. Cabinet Regulations prescribes, that for application for aid for biogas plants building (40% of eligible expenses) owner should have at least 30% of feedstock for biogas plant animal by-products and derived products not intended for human consumption. Special 'waste' component is proposed to include in feed-in tariff for purchase of electricity produced from waste biomass according to draft Renewable Energy Law. Properly calculated resources are necessary for stable round year running of biogas cogeneration plant to fulfill the obligations on selling of electricity to system operator or heat to consumers. Data on biomass resources, including manure, are important also for energy strategy planning at municipal, regional and state level.

Materials and Methods

Investigation is based on assumption that in the immediate future economically viable anaerobic digestion plants can be constructed at farms having livestock more than 100 livestock units. Livestock population data characterized by subgroup were collected. The farms having at least 100 cattle (horses), 1000 pigs (oats, goats) or 5000 poultry were incalculated in every municipality as potential manure supplier for biogas plants in planning region Latgale. Predominant method for cattle manure handling is the solid litter manure collection and storage system in planning region Latgale traditionally. Manure output from livestock and poultry in municipality (region) in a year was calculated as follows:

$$M = \sum_{n=1}^{i} N_i \cdot m_i \ , \qquad (1)$$

where:

- M – livestock (animals and poultry) manure produced in municipality (region), t.
- n – Number of specified groups of livestock population in municipality (region),
- N_i – average number of livestock (animals and/or poultry) present year-round within i^{th} group of livestock,
- m_i – manure produced per one head in a year in the i^{th} group of livestock, t,

Average manure production per one dairy cow is dependent on cow's milk yield and calculates help by regression equation obtained from data on normative manure output for dairy cows, (Priekulis J. et al., 2008):

$$m_1 = 0.0024 \cdot Y_d + 0.447 , \qquad (2)$$

where:

m_1 – average manure production per dairy cow in municipality in a year, t yr^{-1},

Y_d – average milk yield per dairy cow in municipality in a year, kg yr^{-1}.

Biogas production from manure potential was calculated as the sum of biogas volumes obtainable from manure produced by all groups of animals in parish (municipality, region):

$$V_B = \sum_{n=1}^{i} N_i \cdot m_i \cdot k_{DMi} \cdot k_{OMi} \cdot v_{Bi} , \qquad (3)$$

where,

V_B – biogas volume, potentially obtainable from manure biomass in parish (municipality, region) in a year, m3,

k_{DMi} – dry matter content in manure produced by i^{th} group of animals in parish (municipality, region),

k_{OMi} – organic matter content in dry matter of manure produced by i^{th} group of animals in parish (municipality, region),

v_{OMi} – specific biogas output from manure organic matter for ith group of animals in parish (municipality, region), m^3 t^{-1}.

Energy of biogas obtainable from manure biomass in municipality (region) was calculated as follows:

$$E_B = \sum_{n=1}^{i} N_i \cdot m_i \cdot k_{DMi} \cdot k_{OMi} \cdot v_{Bi} \cdot e_{Bi} , \qquad (4)$$

where,

E_B – energy potential obtainable from biogas produced from manure, kWh,

e_{Bi} – specific heat energy content of biogas obtained from manure produced by i^{th} group of animals (poultry), kWh m^{-3}.

Electric power of cogeneration unit(s) utilizing biogas from manure in parish (municipality, region) was calculated as follows:

$$P_e = \frac{E_B}{k_e \cdot T_C} , \qquad (5)$$

where,

P_e – rated electric power of cogeneration units will be installed in parish (municipality, region), kW,

k_e – coefficient of electric efficiency of cogeneration unit, $k_e = 0.4$,

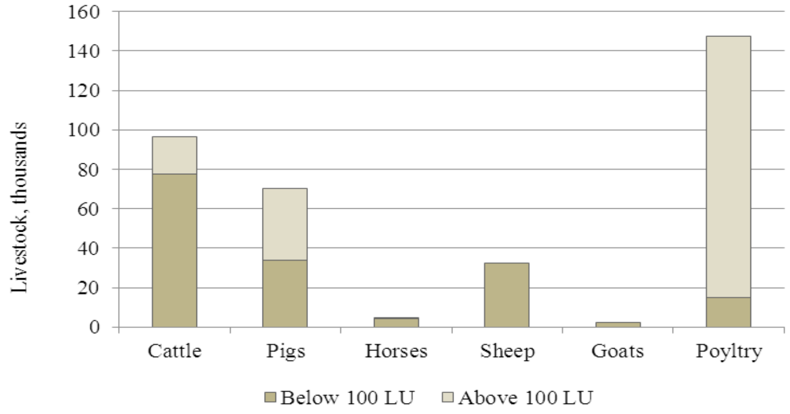
T_C – number of hours in a year while cogeneration units operate at a rated capacity, $T_C = 8000$ h.

Number of animals (poultry) in farms having more than 100 livestock units and average milk production from dairy cows were obtained from databases of State agency Agricultural Data Centre (LDC). General data on number of animals, e.g. average number of animals in herds, total number of animals in planning regions were obtained from databases of Central Statistical Bureau (CSB). Some specified data on animals, e.g. actual number of pigs in piggeries were obtained help by interviews. Data on manure characteristics were derived both from experimental data, as well as from literature, including normative documents and scientific publications.

Results and Discussion

Investigated total number of cattle, pigs, horses, sheep and goats was 206.7 thousand located in 22.8 thousands barns in Latgale planning region. Number of poultry was 147.6 thousands, situated in 795 barns in Latgale. There were 76 cattle farms, 7 piggeries, 1 horse stable and 1 poultry farm having livestock above 100 livestock units (LU) in planning region Latgale. There were investigated 55 cattle herds with number of animals in range 100-300 heads, 19 herds with number of animals in range of 300-500 heads and 4 herds with number of animals more than 500 heads in region Latgale in year 2011. Average size of cattle herd was 155, 382 or 802 heads within range of 100-300, 300-500 or above than 500 cattle per herd respectively. Distribution of number of animals in herds in respect of the accepted threshold value of 100 livestock units in planning region Latgale is shown in Fig.1. Around 20% of cattle, 2% of horse, 52% of pigs and 91 % of poultry are included in large herds (more than 100 LU) suitable for biogas plants building nearby those farms. Pigsties with more than 1000 animals were accounted in 7 farms in planning region Latgale, including three pigsties located in Rēzeknes municipality and in each single pigsty located in Aglonas, Dagdas, Daugavpils and Ludzas municipality. No one sheep or goats herd above 100 LU exists in planning region Latgale in a year 2011.

Aiming to improve accuracy of manure resources evaluation, all the suitable animals (cattle, pigs, horses and poultry) was divided in eleven groups according to its manure production capability per one head. The number of livestock within specified groups in planning region Latgale, coefficients for dry matter, organic matter, biogas production and heat energy content of biogas are presented in



Source: State Agency Agricultural Data Centre

Figure 2. **Number of animals in herds below and above 100 LU in planning region Latgale**

Table 1

Groups of livestock, number of livestock, energy content of biogas, manure and biogas characteristics

Group number	Group characteristics	Number of heads in group in Latgale	Manure production per head, t yr^{-1}	Manure in Latgale, t	Dry matter content	Organic matter content in dry matter	Biogas output from manure, m^3 t^{-1}	Heat energy of biogas, kWh m^{-3}
i		N	mi	M	k_{DM}	k_{OM}	v_B	e_B
1	Dairy cows	8407	$0.0024\ Y_D + 0.447$	100400	0.18*	0.86**	300	5.8
2	Calves (0-6 month)	3367	2.6*	8750	0.18*	0.86**	300	5.8
3	Heifers (6-12 month)	1338	8	10700	0.18*	0.86**	300	5.8
4	Young cattle 12 – 24 month	3525	11.1	39130	0.18*	0.86**	300	5.8
5	Cattle (more than 24 month, except dairy cows)	2372	12*	28460	0.18*	0.86**	300	5.8
6	Horses	100	8*	800	0.3*	0.86**	300	5.8
7	Piglets	10409	0.4*	4164	0.07**	0.86**	500	6
8	Sows	2392	2.5*	5980	0.08**	0.86**	500	6
9	Gilts and boars	1243	2.5	3108	0.09**	0.86**	500	6
10	Fattening pigs	22507	2*	45104	0.06**	0.86**	500	6
11	Poultry	132600	0.022*	2917	0.45	0.75	510	6

*Sources: *(Priekulis at al., 2008), **(Дубровский at al., 1988)*

Table 1. For purpose of this investigation, prevailing manure handling technology was litter manure collection for cattle, horses or poultry, and slurry collection for pig manure in planning region Latgale.

Manure production by animals in different groups, manure characteristics, specific biogas output from organic matter of manure and specific energy content of biogas from different groups of animals from farms with more than 100 LU in planning region Latgale are presented in Table 1.

Average values of manure production m_i per 1 head in a year for all groups of livestock, except dairy cows, are given in Table 1. Average manure production m_i per dairy cow in a year was calculated according to equation (2) for all parishes and

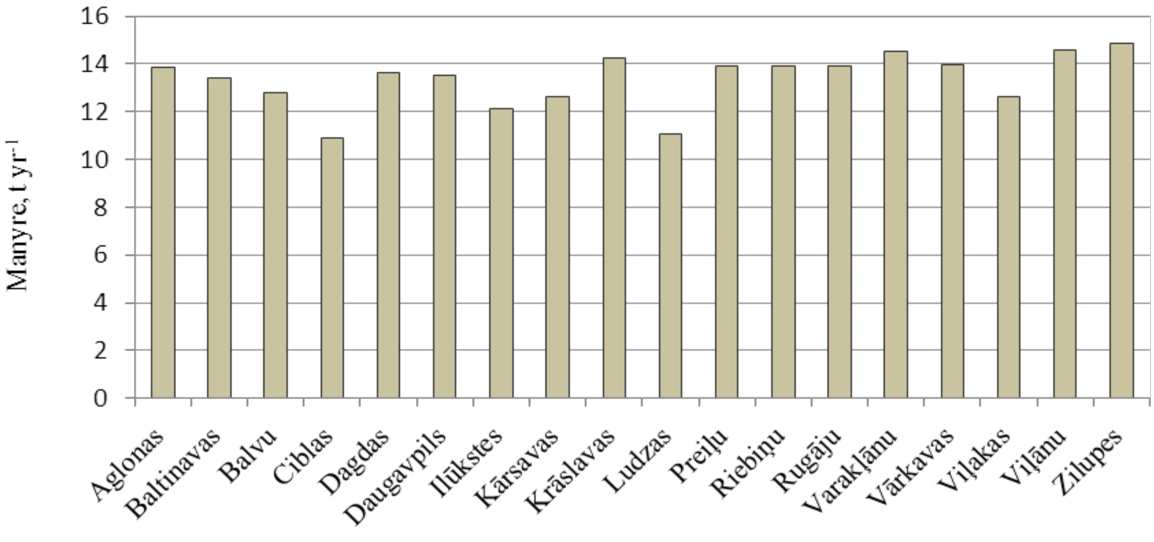


Figure 2. **Average manure production per one dairy cow in a year in municipalities of Latgale**

Table 2

Manure dry matter, biogas, energy and power of cogeneration units in municipalities in Latgale

Municipality	Dry matter	Biogas	Biogas	Biogas energy	Electric energy	Electric power of cogeneration unit
	t	Thous. m^3	%	MWh	MWh	MW
Aglonas	1550	502	4.5	2964	1186	0.148
Balvu	969	250	2.2	1450	580	0.072
Ciblas	231	60	0.5	346	138	0.017
Dagdas	2331	750	6.7	4426	1770	0.221
Daugavpils	4983	1606	14.3	9491	3796	0.475
Ilūkstes	2744	708	6.3	4106	1642	0.205
Krāslavas	1459	376	3.4	2183	873	0.109
Līvānu	2291	591	5.3	3429	1371	0.171
Ludzas	918	350	3.1	2086	835	0.104
Preiļu	891	230	2.0	1333	533	0.067
Rēzeknes	7920	2302	20.5	13479	5391	0.674
Riebiņu	3554	915	8.2	5309	2124	0.265
Rugāju	1335	344	3.1	1997	799	0.100
Vārkavas	2677	691	6.2	4006	1602	0.200
Viļānu	5972	1541	13.7	8936	3574	0.447
Sum	**39823**	**11216**	100	**65542**	**26217**	**3.277**

municipalities in planning region Latgale. Evident differences between municipalities were obtained in manure production per one dairy cow in a result of different levels of milk yields, Fig.2.

Manure, biogas, energy and constant electric power of cogeneration units for 11 groups of animals were calculated help by formula (1-5) in every parish, municipality, and in whole region Latgale, see Table 1. Summary manure dry matter, biogas, energy and constant electric power of cogeneration units within municipalities in Latgale are presented in Table 2.

Biogas production potential is strongly varying between municipalities. Highest biogas potential have municipality Rēzekne, as there were located many large cattle and pig farms, Fig. 3.

Biogas potential from cattle, pigs, horses and poultry manure in planning region Latgale, calculated help by equation (3), is presented in Fig. 4.

The share of biogas potential obtainable from manure is largest for cattle manure 77.6%, followed by

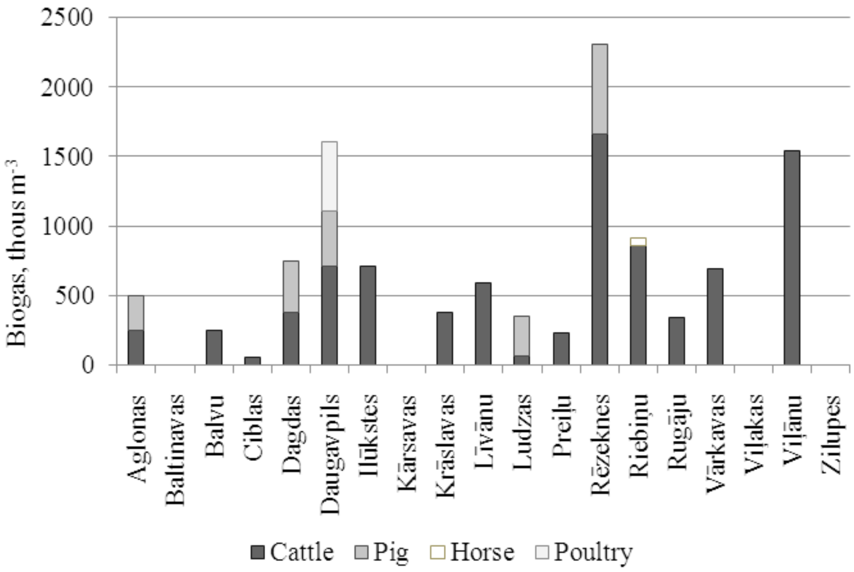


Figure 3. **Biogas production potential from livestock manure in municipalities of Latgale**

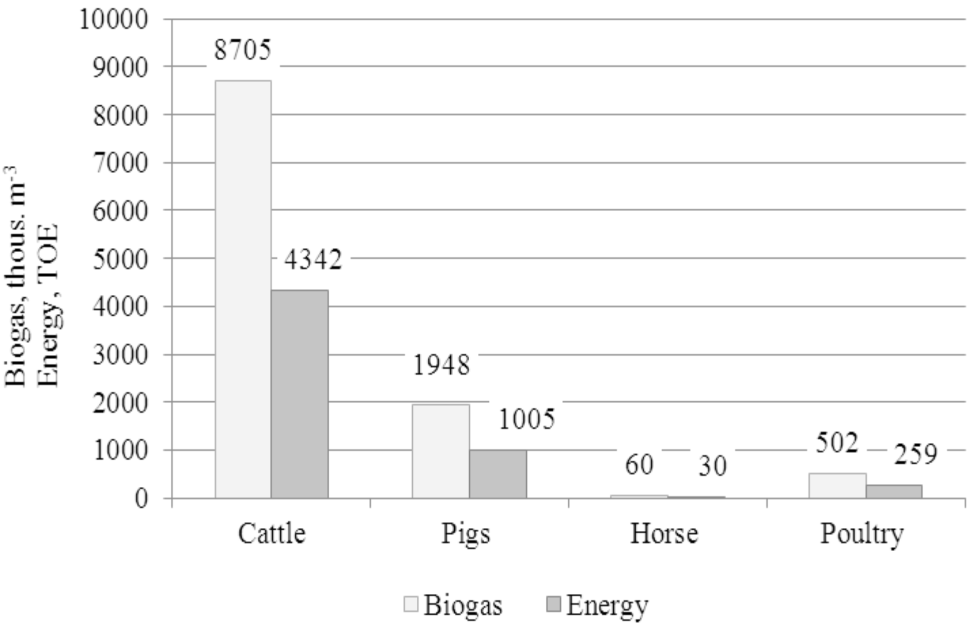


Figure 4. **Biogas and energy potential from utilizing of different manure in planning region Latgale**

pigs 17.4%, poultry 4.5% and horses 0.5% in planning region Latgale in 2012.

Summary constant electric power of cogeneration units in 25 most prospective parishes in Latgale are presented in Fig. 5.

The most perspective was the building of biogas plant in parish Viļāni, as there was located large dairy farm. The electric power of recently commissioned cogeneration unit is 0.95 MW, or 2.7 times larger to compare to biogas potential obtainable solely from manure in parish Viļāni. Rest of the needed feedstock for this cogeneration plant is provided by plant biomass, e.g. cereals, perennial grasses, maize, other energy crops or biomass from unused agricultural areas.

Economically feasible biogas production from manure is possible in 47 parishes from 151 in planning region Latgale. It is reccomended to include in feedstock, apart of manure, the different local biomass, e.g. maize, perennial grasses and legumes, straw, reed, waste biomass from food industry, biodegragable part of municipal wastes, aiming to increase economical viability for potential biogas projects and to provide stable round year running of biogas cogeneration plants.

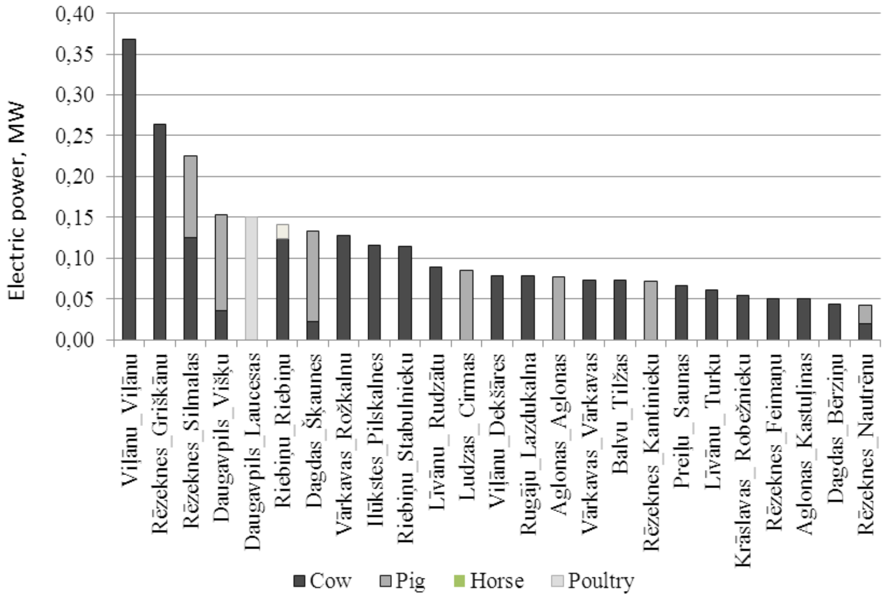


Figure 5. **Electric power of installable cogeneration units in most prospective parishes for utilizing of biogas produced from different manure in planning region Latgale**

Conclusions

Biogas potential obtainable from livestock manure was 11.2 million m^3, including 77.6% from cattle 17.4% from pigs, 4.5% from poultry and 0.5% from horses in planning region Latgale.

Manure dry matter available for economically justified biogas production was 39823 t in planning region Latgale in 2011.

Largest biogas potential of 2.3 million m^3 was obtainable in municipality Rēzekne, where located 20.5% of biogas potential from manure in planning region Latgale.

Electric power obtainable from biogas production from manure was varying from 0.008 MW in parish Skrudalienas, municipality Daugavpils to 0.37 MW in parish Viļāni, municipality Viļāni in planning region Latgale.

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ANALYTICAL MODEL AND SIMULATION OF OXYGEN SOLUBILITY IN WASTEWATER

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Abstract
The research paper discusses oxygen transfer process in the water of the sewage biological treatment system, and provides mathematical model and simulation of oxygen solubility process in wastewater. Oxygen supply to wastewater is one of the most important components of the biological treatment process from energy point of view because of substantial energy consumption and need for continuous operation. Thus, understanding process of oxygen transfer and development of analytic expressions describing oxygen solubility under different environmental conditions is cruical. Impact of temperature, air pressure, oxygen concentration in supplied air, composition of dissolved chemicals, and air supply unit submerging depth was taken into account, and the mathematical model of oxygen solubility in water was compiled. Oxygen solubility process was simulated using Matlab `Simulink` software. Analytical model of oxygen solubility in water can be used in wastewater treatment plants in order to develop an improved control system for the aeartion system, which would result in a decrease in energy consumption.
Key words: oxygen solubility, mathematical modeling, simulation, wastewater aeration, control.

Introduction

Modern wastewater treatment systems (WWTS) utilize bological sewage treatment approach, in which activated sludge is being used. Activated sludge is a process in sewage treatment in which air or oxygen is forced into sewage liquor to develop a biological environment consisting of different microorganisms which are processing the pollutents of the sewage. In the process, large quantities of air are bubbled through wastewaters that contain dissolved organic substances in open aeration tanks. Air is being supplied to the WWTS using air blowers driven by asynchronous electric motors, and this system is the largest energy consumer in WWTS (accounting 40–80% of all WWTS energy consumption, value varies depending on aeration technology used and WWTS geographical location) (Šnīders, 2004; Wang, 2007), and precise air supply to WWTS and dissolved oxygen control are becoming very important tasks taking into account the global trend of energy prices increase.

Oxygen is required by bacteria and other types of microorganisms present in the system to live, grow, and multiply in order to consume the dissolved organic `food`, or pollutants in the waste. As the wastewater composition, physical, chemical properties and waste concentration, as well as external environment (temperature, moisture content, air presure and composition, etc.) vary along time, it is very important to create the system which could supply appropriate amount of oxygen, at the same time using an economically affordable energy amount.

Optimal control of the operation of WWTS electric motors is very important in order to obtain the optimum technical and economical solution, while at the same time, optimal control requires the creation of appropriate mathematical model which high quality and realistic process adequately addresses the oxygen delivery. Lack of a common mathematical model that describes the non-stationary oxygen transfer process in the aeration tank sets limitations for the sewage treatment plant designers and operators to use the optimal (energy-efficient and high quality) aeration engineering system control algorithm, which takes into account the dynamics of the aeration tank. Studies on oxygen solubility in wastewater had been looking at influence of different individual factors, but no complex analytic model taking into account the set of factors affecting solubility of oxygen was developed and used in wastewater aeration control systems.

Oxygen dissolving in water is a complicated physical process influenced by different factors. In order to evaluate the aerotank dynamic response, it was necessary to introduce in the mathematic model of aerotank the analytic equation of oxygen solubility, which takes into consideration the main influencing factors – oxygen concentration in the air supplied, wastewater temperature and salinity, as well as air pressure, and to validate the simulation model.

Materials and Methods

Observations of oxygen concentration in air prove substantial seasonality. Oxygen concentration change diapason is between 20.84% and 20.97 %, showing lowest scores during winter (BIO2 International, s.a.). Oxygen concentration fluctuations are considerable, and this factor will be included in oxygen solubility formula, which then will be used for the development of highly efficient wastewater aeration control system. The main reasons for such seasonality in oxygen concentration in air are the following: plants are producing oxygen mostly in warm season, oxygen solubility in water increases due to water temperature decrease, as well as seasonal changes in human activities – increased oxygen consumption due to increased fuel burning for heating in cold weather. Observations also confirm assumption that oxygen concentration in urban area is lower than in countryside and in forests (Moiseeva, 1995; Keeling, 1998).

Experimental research revealed that the water of open basins in summer (temperature 21°C) contains on average 13 g·m^{-3} of nitrogen (N_2), 9 g·m^{-3} of oxygen (O_2), and 35 g·m^{-3} of carbon dioxide (CO_2) (Meck, s.a.; Mack, s.a.). Saturation level of gases dissolved in water differs, and depends on water temperature (Colby, s.a.; Colt, 1984). With water temperature increase the solubility of gases in water decreases (Colt, 1984; FAO, 1998). Saturation level of oxygen solubility usually is being acquired from ready-made tables, which were developed from experimental data (Colt; 1984; YSI, s.a.). There are only few analytic expressions available currently (Weiss, 1970; Garcia, Gordon, 1992; Tromans, 2000; Sniders, 2003), which have very limited use in automatic conrol systems.

Wastewater contains a mixture of different dissolved salts, suspended solids, and live creatures – microorganisms, bacteria, etc. Experimental research shows that concentration and composition of salts dissolved have direct impact on oxygen concentration in water – the higher is salinity, the lower is oxygen saturation level in water (Colt, 1984). For simplified oxygen saturation calculations, usually non-dimensional coefficient is being introduced, which should take into account wastewater salinity (YSI, s.a.), but the quality of the simulation is questionable. Obviously, such approach does not allow adjusting oxygen saturation level neither to specifics of particular WWTP with its own composition and concentration of dissolved salts, nor to changes in dissolved salts composition and concentration.

Observations (Colt, 1984) show that atmospheric pressure has an impact on oxygen solubility in water – with diminishing atmospheric pressure the oxygen solubility in water decreases. No analytical expressions were find which describe this solubility impacting factor.

Air supply to aerotank must be provided with overpressure, if aeration is provided from a bottom of aerotank, because wastewater layer above the diffuser creates overpressure, and air blower must provide air pressure which is larger than that created by the wastewater layer – air pressure must be higher than the pressure in the diffuser submerging depth *h* in wastewater.

Water density changes have an impact on the necessary air blower output pressure. At the same time water in its liquid stage substantially differs from other liquids – its density changes nonlinearly with the changes in water temperature. None of the known oxygen solubility models takes into account this nonlinear impact.

Oxygen solubility process was simulated using Matlab `Simulink` software in order to evaluate how the variables influence this process.

Results and Discussion

Regression analysis application on the experimental data gathered about the relation between the water temperature and oxygen saturation in water (Colt, 1984) revealed the formula describing this relation:

$$C_S(\Theta) = 14.208 \cdot \exp\left(-0.0219 \cdot \Theta\right). \qquad (1)$$

The obtained exponential expression which joins together oxygen saturation in water $C_S(\Theta)$ and temperature Θ (in Celsius degrees) with high accuracy describes the interdependence of the two factors (R^2= 0.997). At the same time it can be used as a basic analytic expression for the development of an oxygen solubility multifactorial model.

Modified analytic expression which takes into account the composition and concentration of dissolved salts in wastewater (using Mack, s.a.; Han, 2002) was created:

$$C_S = C_0 \cdot \exp\left(\sum_{i=1}^{n} K_i c_i\right)^{-1}, \qquad (2)$$

where

- C_0 – oxygen solubility in clean water, g·m^{-3};
- i – index of the ione dissolved in water;
- K_i – semiempyrical constant for the indexed ione;
- c_i – molarity of the indexed ione in water solution;
- C – oxygen solubility in water with dissolved indexed iones, g·m^{-3}.

An analytic expression which describes interrelation between air pressure and oxygen solubility was developed using a modified Henry's formula:

$$C_x = p_x \cdot k_H^x = p_x \cdot A \cdot N_A \cdot \alpha^x, \qquad (3)$$

where

- C_x – solubility of gas x, g·m^{-3};
- k_H^x – Henry's constant for gas x (particularly – for oxygen), (g/m^3)·Pa^{-1};
- p_x – partial pressure of gas x (in this formula – oxygen), Pa;
- N_A – Avogadro's constant, mol^{-1};
- A – coefficient taking into account oxygen density;

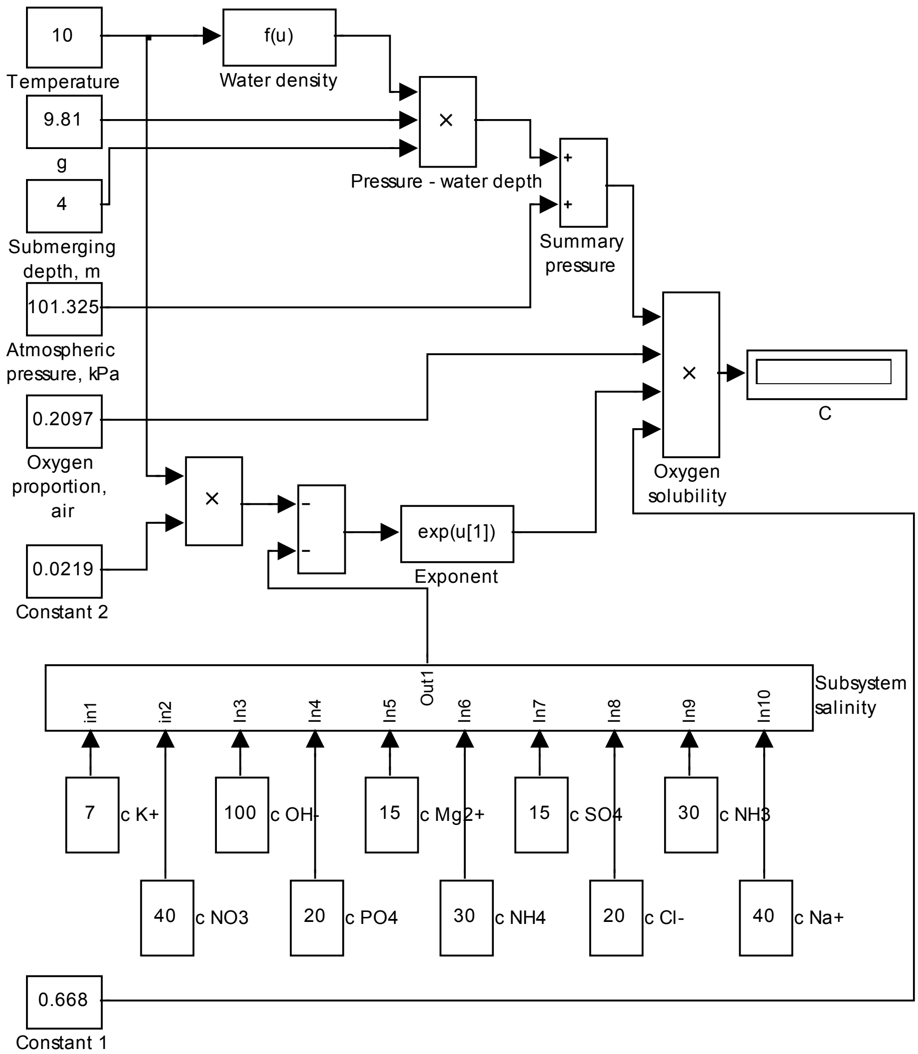

Fig. 1 The virtual model of oxygen solubility

α^x – Bunzen's coefficient for oxygen, $m^3 \cdot mol^{-1}$.

A formula describing Bunzen's coefficient for oxygen was developed using experimental data (Weiss, 1970) and applying nonlinear regression model:

$$\alpha = 4.91 \cdot \exp(-0.0219 \cdot \Theta). \quad (4)$$

Gas pressure impact on gas solubility can be described using a modified formula (Broecker, Peng, 1982; Sawyer, McCarty, 1978):

$$C_1 \cdot p_1^{-1} = C_2 \cdot p_2^{-1}, \quad (5)$$

where

C_1 and C_2 – gas solubility for two different pressures, $g \cdot m^{-3}$;

p_1 and p_2 – gas pressures, Pa.

A formula describing complex impact of air pressure and temperature was created using expressions (3), (4) and (5):

$$C = p_x \cdot A \cdot N_A \cdot \alpha^x \cdot 4.91 \cdot \exp(-0.0219 \cdot \Theta). \quad (6)$$

An expression describing the dependence of the air blower output pressure on temperature and the air diffuser submerging depth, and taking into account the nonlinear dependence of water density on temperature was created:

$$p_h = \rho \cdot g \cdot h = (-0.006 \cdot \Theta^2 + 0.0365 \cdot \Theta + 999.91) \cdot g \cdot h, \quad (7)$$

where

p_h – water pressure in depth *h* (required air blower pressure), Pa;

ρ – water density, kg·m⁻³;

h – air diffuser submerging depth, m;

g – gravity constant, 9.81 m·s⁻².

A mathematic model which describes the interrelation between oxygen solubility in wastewater and the scope of external factors – air pressure, oxygen concentration in air, wastewater salinity and the composition of dissolved iones, wastewater temperature, as well as air diffusers submerging depth - is presented in the formula developed by the authors of the presented research:

$$C_S = C(r_{O_2}, p_a, \Theta, K, c_i, h) = \frac{0.668 \cdot r_{O_2} \cdot \left(p_a + \left(-0.006 \cdot \Theta^2 + 0.0365 \cdot \Theta + 999.91\right) \cdot g \cdot h \cdot 10^{-3}\right)}{\exp\left(\sum K_i c_i + 0.0219 \cdot \Theta\right)}, \quad (8)$$

where

r_{O_2} – proportion of oxygen in the air;

p_a – atmospheric pressure.

Virtual model of oxygen solubility using formula (8) and software package Matlab subprogram Simulink was developed (Fig.1) for further exploration of the dynamic response of the wastewater aerotank.

Main parts of the virtual model are the following:

– `Temperature` block allows establishing and change wastewater temperature, ºC;
– `g` block sets the gravity constante g=9.81 m·s⁻²;
– `Submerging depth` block allows establishing the aeration diffusers submerging depth, m;
– `Atmospheric pressure` block sets atmospheric pressure, kPa;
– `Oxygen proportion` block sets oxygen proportion in supplied air;
– blocks `Constant 1` and `Constant 2` introduce constants 0.668 and 0.0219;
– `Water density` block provides re-calculation of water density according to the water temperature;
– `Exponent` block takes into account the exponential characterictics of the solubility;
– blocks with the indicies `c..` present the ionic composition of the waste in the wastewater, g·m⁻³;
– blocks `Pressure – water depth`, `Subsystem salinity`, `Summary pressure` and `Oxygen solubility` are used for mathematic operations in order to calculate the oxygen solubility.

Oxygen solubility simulation was provided using data from real WWTS. They were the following:

– wastewater temperature Θ=10˚C;
– aeration diffusers submerging depth h=4m;
– atmospheric pressure 101.325 kPa;
– oxygen proportion in air $r_{O_2} = 0.2097$;
– wastewater ionic composition – c_{K+}=7 g·m⁻³, c_{OH-}=100 g·m⁻³, c_{Mg2+}=15 g·m⁻³, c_{SO42-}=15 g·m⁻³, c_{PO43-}=20 g·m⁻, c_{Cl-}=20 g·m⁻³, c_{Na+}=40 g·m⁻³, c_{NH3}=30 g·m⁻³, c_{NH4-}=30 g·m⁻³, c_{NO3-}=40 g·m⁻³.

Simulation steps :

– initial conditions were established, and the first simulation provoided;
– the following simulation pattern for further simulations was used:
  1. aeration diffusers submerging depth change – depth increase by 1 m (other parameters the same*Ceteris Paribus(CP*));

Table 1

The results of oxygen solubility simulation

Simulation No.	Condition change	Oxygen solubility change , %
1	Initial conditions	100%
2	Aeration diffusers submerging depth h=5m	106.98%
3	Aeration diffusers submerging depth h=6m	113.95%
4	Wastewater temperature Θ=+15˚C	102.11%
5	Wastewater temperature Θ=+20˚C	91.50%
6	Atmospheric pressure p_g=100.725 kPa	90.92%
7	Atmospheric pressure p_g=100.225 kPa	90.35%
8	Oxygen proportion in air r_{O_2}=0.1997	86.04%
9	Oxygen proportion in air r_{O_2}=0.1897	81.73%
10	Increase in wastewater salinity by +100% (peak load)	78.31%

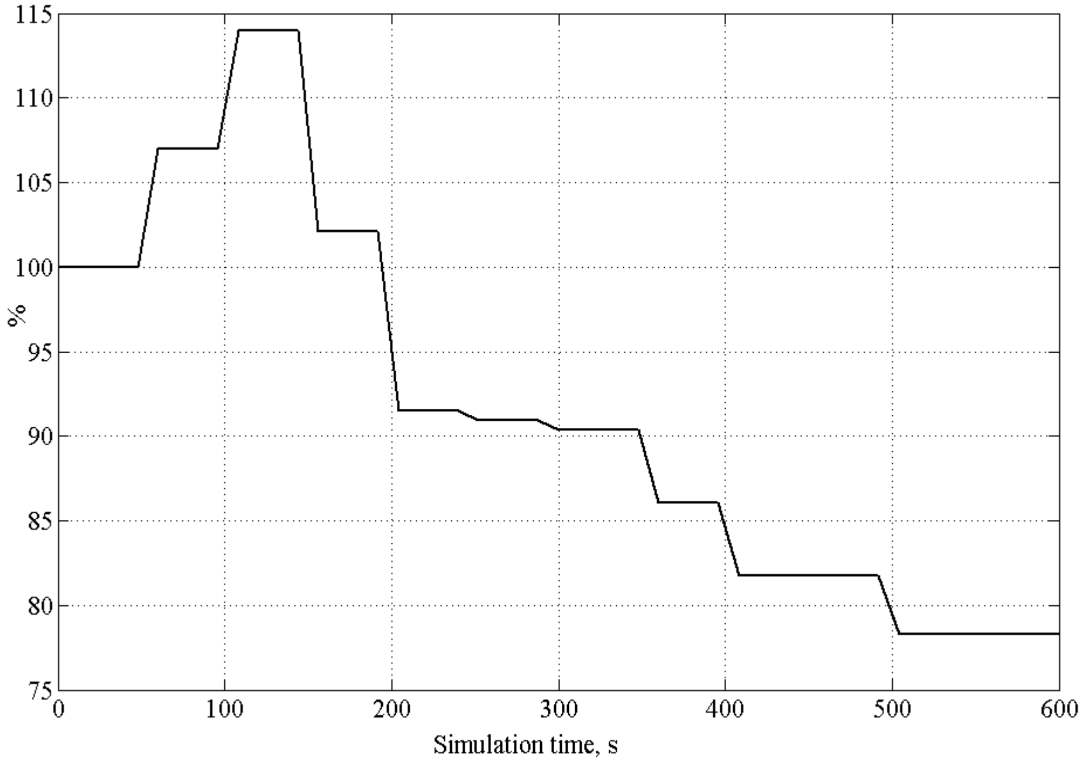

Fig.2 The graph of oxygen solubility simulation results

2. aeration diffusers submerging depth change – depth increase by additional 1 m;
3. wastewater temperature increase by +5˚, Θ=+15˚C, (*CP);*
4. wastewater temperature increase by additional +5˚, Θ=+20˚C, (*CP);*
5. atmospheric pressure decrease by –0.5 kPa (p_g=100.725 kPa);
6. atmospheric pressure decrease by additional –0.5 kPa (p_g=100.225 kPa);
7. oxygen proportion in air decreases by 0.01 (r_{O_2}=0.1997);
8. oxygen proportion in air decreases by aditional 0.01 (r_{O_2}=0.1897);
9. increase in wastewater salinity by +100% (peak load).

Simulation results are presented in Table 1 and Fig. 2.

Conclusions

The analytic expression developed by the authors includes all the important variables influencing oxygen solubility in water. It can be used for the development and design of wastewater aeration control systems.

The virtual model of oxygen solubility developed in Mathlab `Simulink`environment can be used to evaluate the influence of the external factors.

Simulation of the analytic expression shows that different factors differently influence the oxygen solubility – increase in the temperature and salinity is decreasing the solubility, at the same time increase in aeration diffusers submerging depth, atmospheric pressure and oxygen proportion are increasing oxygen solubility.

The analytical model of oxygen solubility in water can be used in wastewater treatment plants in order to develop an improved control system for the aeartion system, which could decrease overall energy consumption of the WWTS.

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BIOGAS PRODUCTION POTENTIAL FROM AGRICULTURAL BIOMASS AND ORGANIC RESIDUES IN LATVIA

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Abstract
The biogas and energy potential from different biomasses is needed to be evaluated, including manure, wastewater sludge, energy plants, and food und biofuel processing wastes in Latvia. Energy crops growing on unused agricultural area are the most important biomass feedstock and its share is around 88% of whole biogas potential in Latvia. Biogas output from different biomass was investigated in laboratory scale digesters operated at 38°C. Biomass mixed with inoculums (fermented cow manure) was investigated for biogas production in sixteen digesters, operated in batch mode at temperature 38±1.0°C. The average methane yield from old grass silage was 248 $l \cdot kg_{DOMadd}^{-1}$ and the average methane content was 48.9%. The average methane yield from chopped oats was 303 $l \cdot kg_{DOMadd}^{-1}$ and the average methane content was 63.1%. The average methane yield from dry fraction of pigs manure was 342 $l \cdot kg_{DOMadd}^{-1}$ and the average methane content was 54.53%. All the investigated biomasses can be successfully cultivated for energy production in Latvia.
Key words: agricultural wastes, anaerobic digestion, biogas, energy crops, methane.

Introduction

In accordance with the National Renewable Energy Action Plan, in 2020 the biogas energy potential should reach 92MW (Support programmes for.., 2012). For the success, it is important to clarify the potential of biogas production from various raw materials, using available and cheaper raw materials first. The Bioenergy Laboratory of Latvia University of Agriculture continues investigation of the potential of biogas production from various raw materials (Biogas Production and.., 2011), and three investigations are shown in this research paper.

1. Old grass silage

Materials, methods and investigation process

The substrates from each type of raw materials and inoculums were analyzed for dry matter, organic matter, ash content and chemical composition. The investigation was measured by using standardized methods (Methodenhandbuch Energetische biomassenutzung.., 2010) (VDI 4630). The raw materials and inoculums were carefully weighed and thoroughly mixed. For all substrates, the same inoculums were used – digestate from a continuous digester. All digesters were connected to the gas storage facilities and taps; the digesters were operating in continuous mode at temperature from 38 to 38.5 °C. Data of gas volume and composition were registered every day. The digesters were agitated every day to reduce the floating layer. The process of fermentation was measured in a single loading mode until the biogas stopped evolving. Also the digestate was weighed and the pH value, dry matter, ash content and organic matter composition were determined.

The raw material used for the investigation was old grass silage that was kept in a trench for more than a year. The scientists (Anaerobic Digestion of.., 2011) and workers stressed that the digesters should be filled in with the silage of good quality like the cows should be fed with it. However, for various reasons, the quality of silage was not suitable for cattle feeding. Therefore, it was important to investigate the yield of biogas that could be obtained from the last year's grass silage.

0.7 l digesters were filled in with 20 g of old grass silage and 0.5 l of inoculums (the accuracy of the measurements was ±0.2 g). All data were entered into the research journal and computer.

Facilities

The dry matter was determined by the Shimazu facility at temperature 120°C, the organic matter was determined by the Nabertherm drying oven at temperature 550°C. As digesters, standard 0.75l vessels were used. The exsiccator Memmert obtained a stable temperature. All-purpose (Universal) exsiccator Memmert (two items) (temperature to 100°C, volume 300 l). The composition of gas was determined by the gas analyzer *GA 2000*. The concentration of methane, oxygen, carbon dioxide and hydrogen sulphide in the biogas, pressure and normal calculated volume of gas were measured. The weighing scales (Kern 16KO2 FKB) were used to determine weights of raw materials and digestate; the pH stationary meter (PP-50) was used to determine the pH value.

Results

The results are shown in Table 1.

The table results show that silage has low contents of dry matter (17.27%) and organic matter.

The optimum contents of dry matter and organic matter for this type of silage is about 30% and 85-93%, respectively.

The results of digestate investigation are shown in Table 2.

Table 1

Results of raw materials investigation

Raw material/digester	pH substr.	TS %	TS g	T %	DOM %	DOM g	Weight g	Total DOM g
Silage GPS R5	7.01	17.27	3.45	27.0	73.0	2.52	520	18.18
Silage GPS R6	7.01	17.27	3.45	27.0	73.0	2.52	520	18.18
Silage GPS R7	7.01	17.27	3.45	27.0	73.0	2.52	520	18.18
Silage GPS R8	7.01	17.27	3.45	27.0	73.0	2.52	520	18.18
Inoculum	7.78	3.77	18.85	16.94	83.06	15.66	500	15.66

Table 2

Results of digestate investigation

Raw material/digester	pH	TS %	TS g	T %	DOM %	DOM g	Weight g
R5	7.39	3.46	17,4	20.71	79.29	13.79	502.80
R6	7.33	4.02	20,6	17.68	82.32	16.96	512.40
R7	7.2	3.85	19,47	21.43	78.57	15.3	505.80
R8	7.2	3.99	20,05	19.52	80.48	16.14	502.60
Inoculum	7.14	3.39	16,81	21.86	78.14	13.13	495.9

Table 3

Biogas and methane yield

Raw material	Biogas, l	Biogas, l/g DOM	Methane max %	Methane l without inoculum	Methane l/g DOM filled in	Notes
Silage R5	1.5	0.294	48.3	0.494	0.196	
Silage R6	1.32	0.222	41.0	0.177	0.07	tp
Silage R7	2.13	0.544	48.9	0.626	0.248	
SilageR8	2.3	0.611	49.0	0.755	0.299	
Inoculum	0.76	0.048	31.3	0.168	0.011	
Average	1.977	0.483		0.625	0.248	

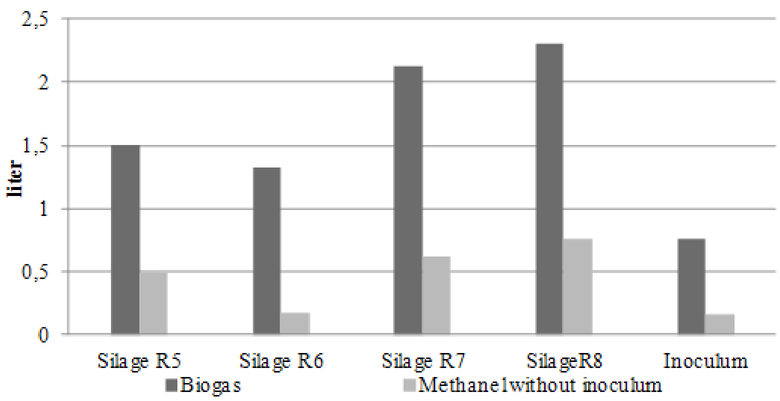

Figure 1. **Biogas and methane yield obtained from old grass silage, l**

The yield of methane and biogas is shown in Table 3 and figures. Results of R6 digester are not reliable and significant due to the technical problems (unregistered gas leak).

The average methane yield obtained from old grass silage is $0.248_{-0,052}^{+0,051}$l/gDOM.

Since the old grass silage quality was bad, it was still possible to obtain a significant amount of methane.

2. Biogas obtaining potential from chopped oats
Materials, methods and investigation process

The oat bran was used as raw material. The bran was carefully shredded and its size did not exceed 1 mm. The process of investigation and facilities are described in the previous investigation.

Results

The results of raw material investigation are shown in Table 4.

The results of digestate investigation are shown in Table 5.

The yield of methane and biogas is shown in Table 6 and figures.

The average methane yield obtained from chopped oats is $0.303_{-0.073}^{+0.062}$l/g DOM.

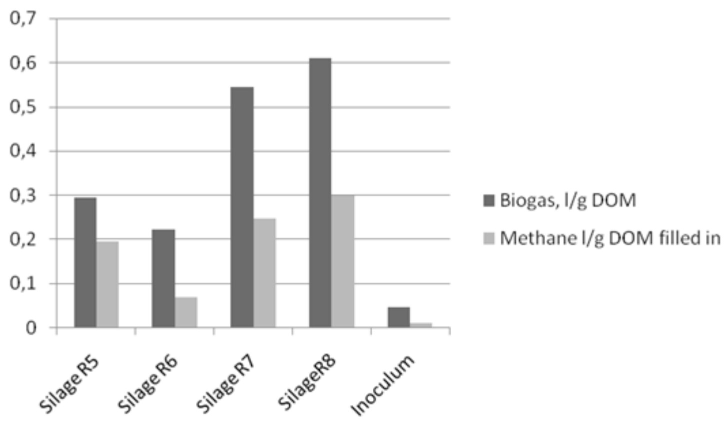

Figure 2. **Biogas and methane l/g DOM obtained from old grass silage**

Table 4

Results of raw material investigation

Raw material/digester	pHsubstr.	TS %	TS g	T %	DOM %	DOM g	Weight g	Total DOM g
Chopped oats R9	7.73	86.6	17.32	4.78	95.22	16.49	520	32.15
Chopped oats R10	7.73	86.6	17.32	4.78	95.22	16.49	520	32.15
Chopped oats R11	7.73	86.6	17.32	4.78	95.22	16.49	520	32.15
Chopped oats R12	7.73	86.6	17.32	4.78	95.22	16.49	520	32.15
Inoculum	7.78	3.77	18.85	16.94	83.06	15.66	500	15.66

Table 5

Results of digestate investigation

Raw material/digester	pH	TS%	TSg	T%	DOM%	DOMg	Weight g
R9	7.11	4.41	22.27	16.56	83.44	18.59	505.1
R10	7.11	4.64	23.09	18.19	81.81	18.89	497.8
R11	7.07	4.82	24.22	16.02	83.98	20.34	502.4
R12	7.1	5.16	25.77	15.96	84.04	21.66	499.4
Inoculum	7.14	3.39	16.64	21.86	78.14	13.0	490.9

3. Biogas obtaining potential from the dry fraction of pigs manure

Materials, methods and investigation process

The dry fraction of pigs manure was used as raw material. This fraction was obtained using the FAN Press Screw Separator. The process of investigation is described in the first investigation.

Results

The results of raw materials investigation are shown in Table 7.

The results of digestate investigation are shown in Table 8.

The yield of biogas and methane is shown in Table 9 and figures.

The average methane yield obtained from the dry fraction of pigs manure is $0.342_{-0.189}^{+0.146}$ l/g DOM.

Table 6

Biogas and methane yield

Raw material	Biogas l	Biogas l/g DOM	Methane max %	Methane l without inoculums	Methane l/g DOM filled in
Chopped oats R9	6.95	0.378	62.4	3.771	0.230
Chopped oats R10	12.0	0.686	62.1	5.970	0.365
Chopped oats R11	7.87	0.433	62.3	4.315	0.263
Chopped oats R12	12.15	0.695	65.6	5.788	0.353
Inoculum	0.76	0.048	31.3	0.168	0.011
Average	9.743	0.548		4.961	0.303

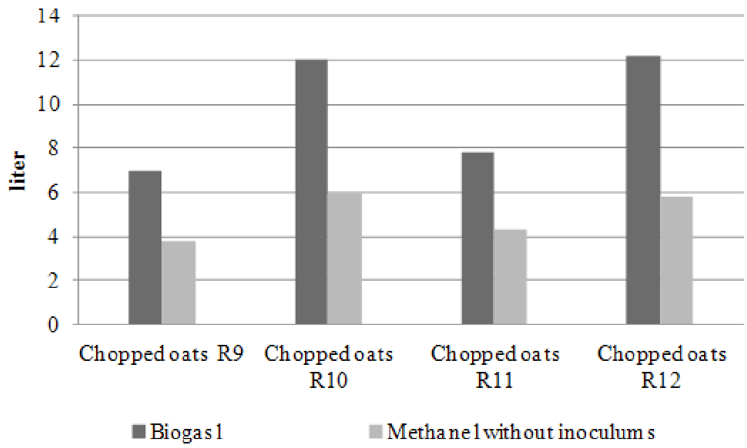

Figure 3. **Biogas and methane yield obtained from chopped oats, l**

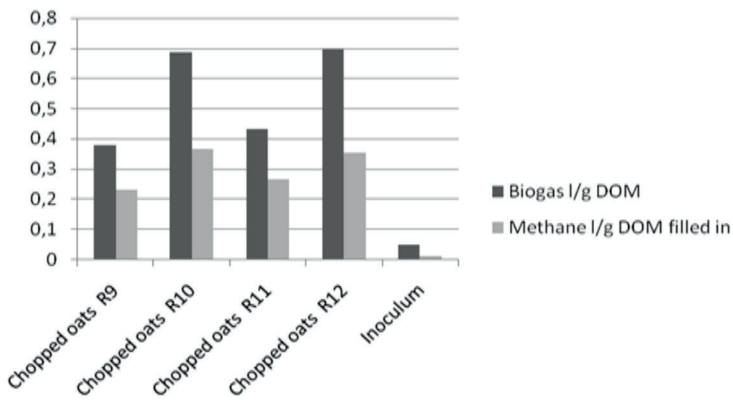

Figure 4. **Biogas and methane yield l/g DOM obtained from chopped oats**

Table 7

Results of raw materials investigation

Raw material/digester	pH substr.	TS %	TS g	T %	DOM %	DOM g	Weight g	Total DOM g
Pig manure R13	7.74	21.16	4.23	8.79	91.21	3.86	520	19.52
Pig manure R14	7.74	21.16	4.23	8.79	91.21	3.86	520	19.52
Pig manure R15	7.74	21.16	4.23	8.79	91.21	3.86	520	19.52
Pig manure R16	7.74	21.16	4.23	8.79	91.21	3.86	520	19.52
Inoculum	7.78	3.77	18.85	16.94	83.06	15.66	500	15.66

Table 8

Results of digestate investigation

Raw material/digester	pH	TS%	TS g	T%	DOM%	DOMg	Weight g
R13	7.08	3.58	18.32	20.23	79.77	14.62	511.80
R14	7.12	3.57	18.38	21.87	78.13	14.36	515.00
R15	7.06	3.84	19.78	17.55	82.45	16.3	515.00
R16	7.08	3.57	18.34	18.45	81.55	14.96	513.80
Inoculum	7.14	3.39	16.64	21.86	78.14	13.0	490.9

Table 9

Biogas and methane yield

Raw material	Biogas l	Biogas l/g DOM	Methane max %	Methane l without inoculums	Methane l/g DOM filled in
Pig manure R13	2.95	0.567	56.8	1.369	0.354
Pig manure R14	4.05	0.852	57.2	1.883	0.488
Pig manure R15	2.33	0.407	49.6	0.706	0.183
Pig manure R16	2.87	0.545	56.0	0.442	0.342
Inoculum	0.76	0.048	31.3	0.168	0.011
Average		0.609		1.319	0.342

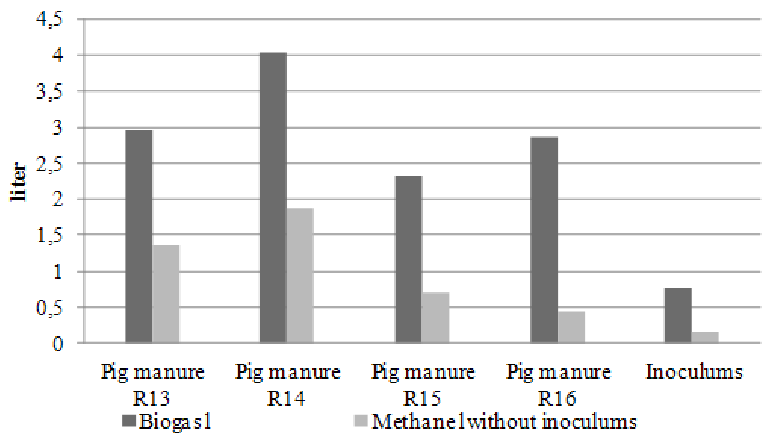

Figure 5. **Biogas and methane yield obtained from the dry fraction of pigs manure, l**

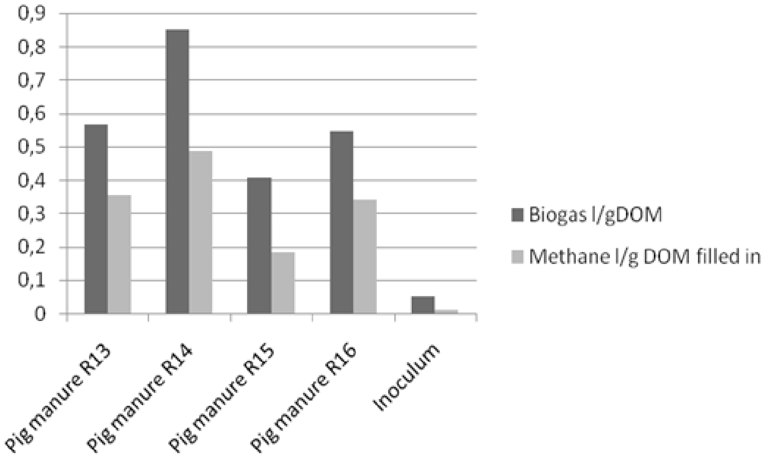

Figure 6. **Biogas and methane yield l/g DOM obtained from the dry fraction of pigs manure**

Conclusions

The investigation shows that good quality silage should be used for biogas production.

If silage quality (silage of lower quality) is not suitable for cattle feeding, it could be used for biogas production, however, the amount of yield will be less than with good quality silage.

Chopped oat bran is a good raw material for biogas production.

The methane yield of 0.303 l/ g DOM is a significant result in comparison with a theoretical optimum.

The methane yield 0.342 l/g DOM obtained from the dry fraction of pigs manure is a good result. This result outperforms the average methane yield from normal pig manure.

It is worth to transport the dry fraction of pigs manure to long distances.

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CO-FERMENTATION OF BIOMASS WITH HIGH CONTENT OF LIGNOCELLULOSES FOR BIOGAS PRODUCTION

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Abstract
More than 20 biogas plants started working in recent time in Latvia. There is need to investigate the suitability of various biomass for energy production. This paper shows results from the co-fermentation of waste water sludge with milk processing whey and different plant biomasses. The co-fermentation process was investigated for biogas production in 50 l digesters, operated in continuous mode at temperature 38±1.0°C. The average methane yield per unit of volatile solids added (VS) from co-fermentation with young willow was 115 $l \cdot kg_{VSa}^{-1}$ and the average methane (CH_4) content was 51.81%. The average methane yield from co-fermentation with chopped barley straw was 284 $l \cdot kg_{VSa}^{-1}$ and the average methane content was 61.47%. All investigated wastes and plants have good biogas yields, and can be successfully cultivated for energy production under agro ecological conditions in Latvia.
Key words: agricultural wastes, anaerobic digestion, biogas, methane, sludge, whey.

Introduction

Latvia cannot provide the country with own produced energy and fossil energy resources are imported from other countries. There are 368500 ha of not used agriculture land in Latvia. Effective use of this land could help to obtain a significant amount of energy. One of the most advanced methods of energy production from biomass is anaerobic digestion. The biogas is a product of great value and its production technology does not increase carbon dioxide emission and is environmentally friendly. In recent years the biogas production is booming also in Latvia. There is need to use different raw materials in biogas plants. Results of co-fermentation investigation on these materials are very important for maintaining a stable anaerobic digestion process at any plant.

Materials and methods

Investigations on laboratory equipment with different raw materials were carried out using one method. At first the equipment was started using inoculum and cow manure, then stable performance of the equipment was reached (beneficial bacteria association was grown for providing a good bioconversion process). Then bacteria were tamed to use co-fermentation products – sludge and whey and finally, the third test material was added in each digester**.** As test materials, raw materials that could be used in a biogas plants were selected. The first stage of the investigation – growing of beneficial bacteria association in each digester lasted up to two months, but the investigation of the addition of the third material – up to one month. This investigation shows the results obtained from facilities after the third material was added.

The raw materials used for the investigation were sludge and whey and other raw materials. The average substrate was taken and the Bioenergy Laboratory of Latvia University of Agriculture determined the composition of the substrate using ISO 6496:1999. The substrates from each type of raw materials were analyzed for dry matter, organic matter, ash content and chemical composition. The analysis was measured by using standardized methods. The dry matter was determined by "Shimazu" facility at temperature 120°C. The raw materials were carefully weighed and thoroughly mixed. All digesters were run using one inoculum – digestate from the cow manure digester.

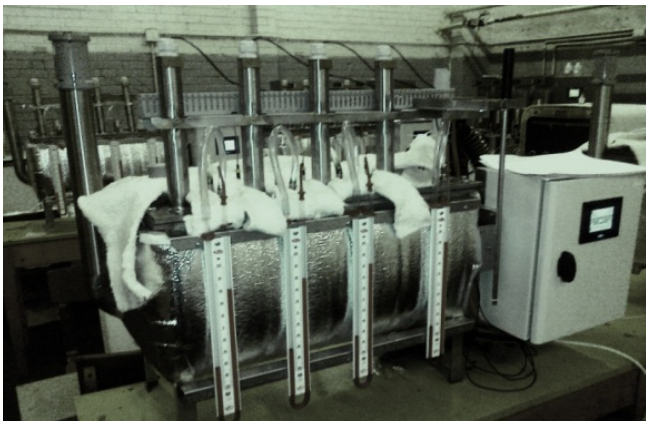
Every day digesters were filled with a specific raw material quantity shown in the research table (the accuracy of the measurements was ±0.2 g for weight). All data were entered into the research journal and computer.

All digesters were connected to the gas storage facilities and taps; the digesters were operating in continuous mode at temperature 38 + 0.5°C. Data of substrate pH value, gas volume and composition were registered every day.

Also the digestate was weighed and the pH value, dry matter, ash content and organic matter composition were determined.

Facilities

The dry matter was determined by the Shimazu facility at temperature 120°C, the organic matter



Pic.1. **Laboratory equipment**

was determined by the "Nabertherm" drying oven at temperature 550°C. The laboratory equipment was used for the research (Picture 1).

The automated heating system obtained a stable temperature. The composition of gas was determined by the gas analyzer "GA 2000". The concentration of methane, oxygen, carbon dioxide and hydrogen sulphide in the biogas, pressure and normal calculated volume of gas was measured. The weighing scales "Kern 16KO2 FKB" were used to determine raw materials and digestate weight; the pH stationary meter "PP-50" was used to determine the pH value.

Results

1. Investigation of raw materials: sludge, whey and sunflower silage

The results are shown in Table 1. YW – young willow; S - sludge; W - whey; TS – total solids; DOM - dry organic matter.

Table 1

Filled in raw materials

Days	Filled material kg				PS, %	DOM from PS %	Ash from PS %	DOM kg
	S	W	YW	Total				
1	0.600	1.003	0.104	1.707	1.707	86.14	13.86	0.1505
2	0.601	1.004	0.102	1.707	1.707	84.30	15.70	0.1480
3	0.602	0.998	0.103	1.703	1.703	84.80	15.20	0.1499
4	0.600	1.002	0.102	1.704	1.704	85.28	14.72	0.1490
5	0.592	1.003	0.100	1.695	1.695	84.84	15.16	0.1487
6	0.603	1.001	0.102	1.706	1.706	86.12	13.88	0.1546
7	0.603	1.002	0.100	1.804	1.804	84.46	15.54	0.1546
8	0.600	1.010	0.100	1.805	1.805	85.67	14.33	0.1536
9	0.610	0.998	0.099	1.807	1.807	85.39	14.61	0.1516
10	0.605	1.003	0.099	1.810	1.810	86.10	13.90	0.1519
11	0.599	1.004	0.099	1.804	1.804	83.90	16.04	0.1455
12	0.601	0.997	0.098	1.796	1.796	84.30	15.70	0.1489
13	0.610	0.999	0.098	1.814	1.814	84.98	15.10	0.1528
14	0.603	1.002	0.097	1.809	1.809	84.30	15.70	0.1449
15	0.601	0.998	0.097	1.799	1.799	84.88	15.12	0.1453
16	0.605	1.008	0.096	1.815	1.815	84.98	15.02	0.1514

Table 2

Biogas and methane yield

Day	Biogas l	Methane l	Average methane content %	Biogas l/kg DOM	Methane l/kg DOM
1	24.30	18.18	74.83	161.42	120.79
2	43.20	24.11	55.82	291.81	162.89
3	50.30	24.49	48.69	335.50	163.36
4	43.40	22.75	52.43	291.21	152.68
5	41.70	21.90	52.52	280.43	147.27
6	43.20	22.29	51.59	279.43	144.17
7	41.60	23.79	57.20	269.02	153.86
8	42.80	23.03	53.81	278.56	149.88
9	41.30	21.11	51.12	272.52	139.30
10	35.60	18.32	51.47	234.32	120.60
11	23.50	12.15	51.71	161.53	83.52
12	25.80	12.54	48.59	173.27	84.20
13	19.00	9.09	47.86	124.31	59.49
14	20.90	10.21	48.84	144.25	70.45
15	10.50	4.31	41.09	72.26	29.70
16	18.50	7.65	41.37	122.19	50.56
Average	$32.85^{+17.45}_{-22.35}$	$17.25^{+12.93}_{-7.25}$	$51.81^{+23.02}_{-10.02}$	$218.21^{+117.25}_{-145.99}$	$114.55^{+48.81}_{-84..85}$

This year yield of young willow was used in the investigation. Young willows with green leaves were chopped in less than 1 cm pieces.

The investigation started on reduced organic load and the principle of gradualness was observed. As the result, the process of co-fermentation was successful and the biogas yield was adequate (Table 2).

2. Investigation of raw materials: sludge, whey and barleys straw.

Barley straw was used as raw material. The straw was carefully shredded and its size did not exceed 1 cm. The amount of filled in raw materials is shown in Table 3.

The C/N ratio of sludge and whey shows that a proportion of nitrogen is greater than a proportion of the carbon. Therefore, the

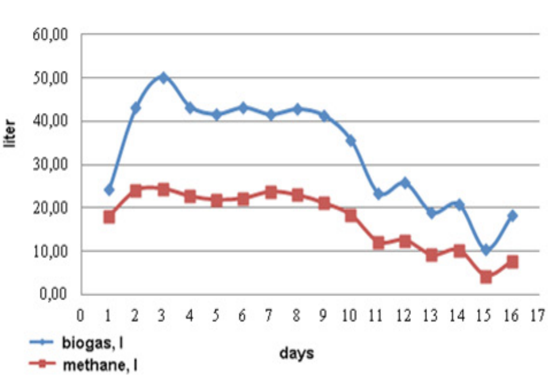


Fig. 1. **Biogas and methane, l**

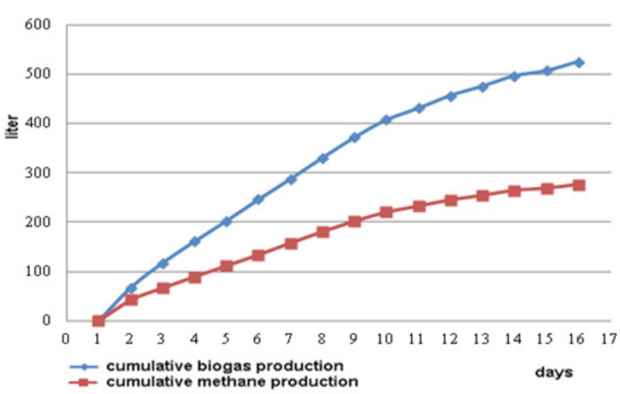


Fig. 2. **Biogas and methane in total, l**

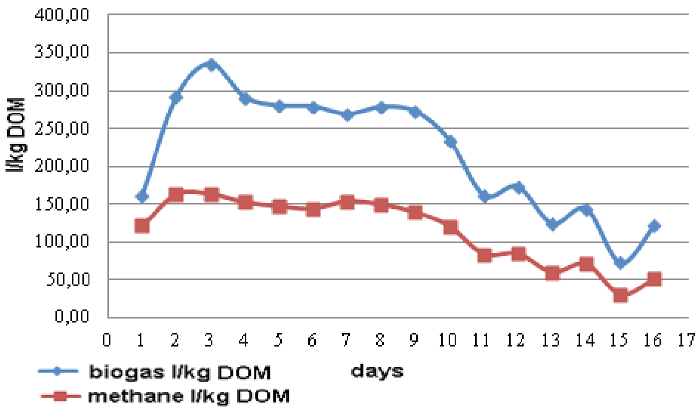


Fig. 3. **Biogas and methane l/kg DOM**

Table 3

Filled in raw materials

Days	Filled in kg					PS %	DOM from PS %	Ash from PS %	DOM kg
	Sludge	Straw	Whey	H_20	Total				
1	0.3	0.05	0.5		0.85	11.48	84.77	15.23	0.0827
2	0.301	0.051	0.503		0.855	11.75	84.93	15.07	0.0853
3	0.304	0.05	0.507		0.861	11.53	84.86	15.14	0.0842
4	0.300	0.051	0.502		0.853	11.31	84.15	15.85	0.0812
5	0.309	0.048	0.5		0.857	11.44	85.01	14.99	0.0833
6	0.300	0.05	0.501		0.851	11.29	85.18	14.82	0.0818
7	0.302	0.046	0.501		0.849	11.37	84.73	15.27	0.0818
8	0.302	0.05	0.499		0.851	11.46	85.07	14.93	0.0830
9	0.301	0.101	0.502		0.904	11.82	85.93	14.07	0.0918
10	0.300	0.099		0.503	0.902	6.57	76.22	23.78	0.0452
11	0.300	0.100		0.51	0.91	6.39	74.32	25.68	0.0432
12	0.300	0.098		0.503	0.901	616	74.26	25.74	0.0412
13	0.300	0.091		0.501	0.892	7.31	71.12	28.88	0.0464
14	0.306	0.097		0.501	0.904	07.11	69.36	30.64	0.0446
15	0.306	0.100		0.51	0.916	6.26	66.50	33.50	0.0382
16	0.305	0.101		0.502	0.908	6.86	68.74	31.26	0.0428

Table 4

Biogas and methane yields

Days	Biogas l	Methane l	Average methane content %	Biogas l/kg DOM	Methane l/kg DOM
1	8.08	4.06	46.13	106.38	49.07
2	23.03	11.23	48.20	273.08	131.61
3	14.5	6.65	45.86	172.12	78.93
4	24.6	10.45	46.55	302.99	141.05
5	37.3	20.48	54.91	447.54	245.74
6	29.3	17.88	61.04	358.02	218.52
7	31	19.10	61.62	379.01	233.57
8	44.6	26.88	60.27	537.58	323.97

Continue of Table 4

Days	Biogas l	Methane l	Average methane content %	Biogas l/kg DOM	Methane l/kg DOM
9	51.1	34.31	67.14	556.53	373.66
10	46.3	31.79	68.66	1025.04	703.79
11	30.4	21.50	70.72	703.44	497.49
12	30.5	21.84	71.60	740.21	530.01
13	21.7	15.80	72.79	468.17	340.80
14	13.2	9.30	70.48	296.15	208.73
15	11.2	7.94	69.67	298.78	208.16
16	16.8	11.39	67.80	392.34	266.00
Average	$27.2^{+23.9}_{-18.4}$	$16.98^{+17.34}_{-12.92}$	$61.47^{+11.33}_{-15.61}$	$441.09^{+583.95}_{-334.71}$	$284.44^{+419.35}_{-235.37}$

straw with a great concentration of carbon improves this ratio. The mode of filling in raw materials was gradually increased and maintained. The results were good and there was no need to correct it. The average organic load of kg·/m^3 was maintained a slightly above the theoretical optimum.

This is explained by the fact that the elements of straw composition have a long decomposition period. Cellulose and hemicelluloses decompose slower and therefore its amount in digestate and dry matter content was increasing.

The yield of methane and biogas is shown in Table 4 and Figures 4 and 5.

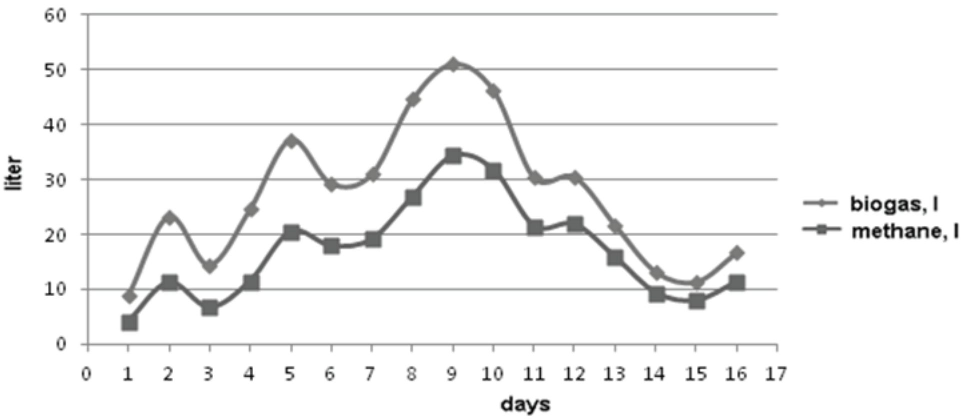


Fig. 4. **Biogas and methane, l**

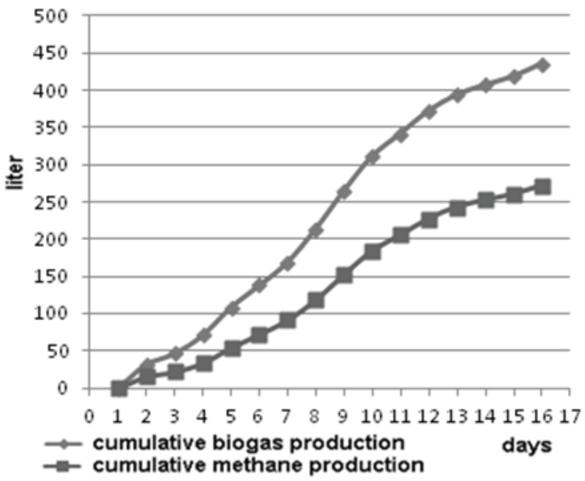


Fig. 5. **Biogas and methane in total, l**

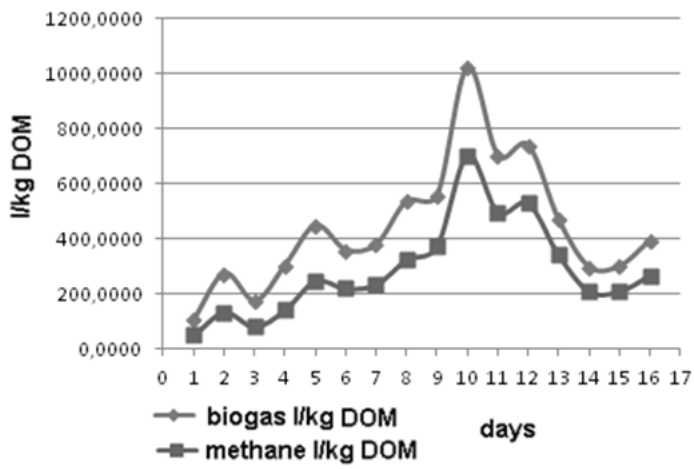


Fig.6. **Biogas and methane, l/kg DOM**

Conclusions

In the sludge, whey and young willow co-fermentation, an average 114.55 $l \cdot kg_{VSa}^{-1}$ methane yield was obtained.

The level of bioconversion could be greater if the increase of raw materials amount is insignificant but stable, yet, it requires a long period of investigation.

Methane yield 284.44 $l \cdot kg_{VSa}^{-1}$ was obtained from sludge, whey and barleys straw.

The process was stable and showed an increasing gas output trend.

The bioconversion level on average was over 60%, but in the final stage of the investigation, it decreased.

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THE INVESTIGATION OF BIOGAS POTENTIAL IN THE VIDZEME REGION

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Abstract
The potential of biogas and available energy have been calculated alone all of Latvia in general until now. The specific character of each region of Latvia was not excluded. In this article more successful biogas plants sites in Vidzeme region have been inspected, where biogas is combusted in cogeneration plants producing electricity and heat simultaneously. The biogas potential is also calculated in Vidzeme region, where it was produced from domestic animal (cattle, pigs and chicken) manure, as well as the unused agricultural available land (AAL) area, the waste water treatment of biological plants of the largest cities, the largest landfills of solid household waste in the region and food processing industry waste. The majority of the total biogas potential makes around 304 million m^3 of biogas per year in Vidzeme region and is derived from the unused AAL area – 225 million m^3 of biogas per year. On average, the biogas potential in each district of the Vidzeme region makes around 12 million m^3 of biogas per year. The calculated amount of electricity that could be produced using biogas is around 700 GWh per year.
Key words: biogas production, animal manure, unused agricultural available land.

Introduction

The estimated draft law in Latvia on the renewable energy provides that in 2020 the local renewable energy sources, such as, sun, wind, wood and biogas, are allocated a significant proportion (40%) of primary energy consumed in the energy market in Latvia. Therefore, first, the estimated potential of renewable energy, which can be obtained in the conditions of Latvia, has to be examined. Unlike other energy sources, biogas is less dependent on weather conditions and it can be envisaged both in season, and more distant future, with no special adjustment of the present results. Until now, the potential of biogas has been studied throughout Latvia, to ignore counties and raw material types.

The Vidzeme region is characterized with the fact that the average of the unused agricultural lands as a proportion of the total agricultural land is quite remarkable 15%. In this case, a significant potential of biogas in Pieriga region will can be obtained using the culture of intensively growing energy crops, such as eastern galega, canary seed, perennial lupine or tall fescue. In addition, to this potential source of biogas food processing plant wastes and cattle manure may also be added.

Till the end of autumn 2011 five biogas cogeneration plants were operating in Vidzeme region:

- Kalsnava bioethanol factory “Biofuels Ltd” (2 MW) in Madona district;
- waste deposit area, “Daibe” (0.35 MW) in Pargaujas district;
- farm Zemturi (0.7 MW) in Valmiera district;
- Bioenergy 08 Ltd in Madona district;
- CONATUS BioEnergy Ltd in Erglu district.

In the near future it is expected that biogas cogeneration plants will start work: BB Biogas Ltd (2 MW) in Belava municipality of the Gulbene district and Agro 3 Ltd (1.5 MW) in Litene municipality.

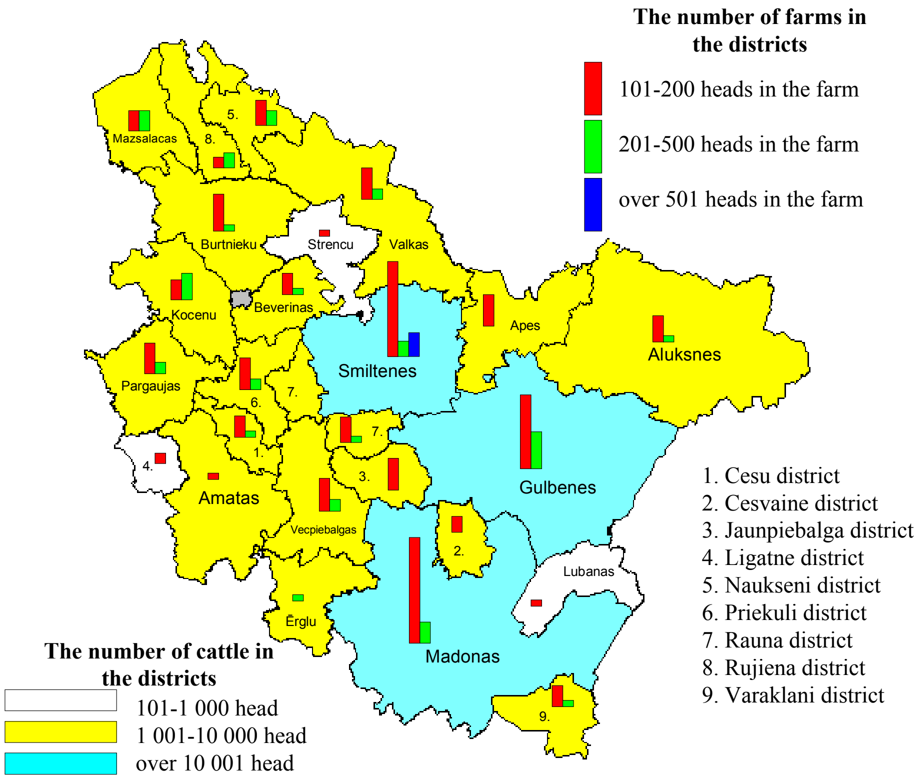
Materials and Methods

When calculating the potential of biogas, the following were taken into account: cattle, pig and poultry manure, food processing industrial waste, the waste water treatment biological plants in the largest cities, the largest landfills of solid household waste in the region, and unused agricultural available land (AAL) area. Technical parameters, which have been considering at the potential of biogas in calculation, are given in table 1.

The domestic animal housings occupied by more than 101 cattle, 1 001 pig and 15 001 chicken were taken into account.

The number of cattle in the districts of the Vidzeme region is mostly balanced 3 500 cattle on average in a district. The majority of cattle is in Madona district – 12 670 cattle, in Smiltene district – 10 655 cattle and in Gulbene district – 9 977 cattle.

Considering the cattle farms, where there are more than 101 cattle, the most such farms are in Smiltene district 27 (19 farms with 101-200 cattle, 3 farms with 201-500 cattle, and five farms with more than 501 cattle), then Madona district follows with 25 farms (20, 5, 0) and Gulbene district with 24 farms (16, 8, 0). Overall, in Vidzeme region there are 138 farms with up to 200 heads in a herd, 45 farms with up to 500 heads in a herd, and 5 farms where there are more than 501 head in a herd (*Database about the number of domestic animals and farms, 2011.).* Figure 1 shows the concentration of cattle and the number of cattle farms in the districts.



Source: Database about the number of domestic animals and farms, 2011.

Figure 1. **Number of cattle and farms in the districts of the Vidzeme region**

Table 1

Animal manures and wastes production and parameters

Biomass type	Manure or waste produced from one animal, t year^{-1}	Dry matter, %	Organic dry matter, %	Biogas produced, m^3 t$_{ODM}^{-1}$
Cow manure	16.80	14	86	300
Pig manure	1.64	15	86	500
Chicken manure	0.06	22	80	500
Unused AAL	9.00		70	540
Sewage sludge	0.015*			400

** - organic matter from one person*

Table 2 summarized the largest food producers from which the gathered waste biogas is potentially obtainable.

The unused AAL area to sows with culture of intensively growing energy crops, for example, galega, the acquired quantity of biogas can be calculated using the following expression:

$$V_B = L \cdot M_{os} \cdot k_d \cdot v_b \qquad (1)$$

where

V_B – the amount of obtainable biogas from the energy crops culture, m^3;

L – unused AAL area, ha;

M_{os} – the obtainable amount of organic solids from the unit of unused AAL area, t ha^{-1} (M_{os} - 8 t ha^{-1});

k_d – the rate of organic matter of biomass conversion,

K_d – 0.7;

v_b – biogas yield from a ton of organic dry matter in the anaerobic process, m^3 t$_{ODM}^{-1}$.

The amount of biogas produced from sewage sludge can be calculated by the expression:

$$V_B = n_i \cdot k_a \cdot m_i \cdot v_b \cdot k_d \quad (2)$$

where

- V_B – the obtainable amount of biogas from sewage sludge, m^3;
- n_i – population in locality;
- k_a – coefficient, which indicates the proportion of the population apartments (houses) connected to the biological treatment plants;
- m_i – the amount of organic dry matter in sludge produced by a person per year, kg $year^{-1}$ (m_i = 15 kg $year^{-1}$);
- v_b – biogas yield from a ton of organic dry matter in the anaerobic process, $m^3\ t_{ODM}^{-1}$;
- k_i – the rate of organic matter of biomass conversion,
- K_i – 0.7.

Results and Discussion

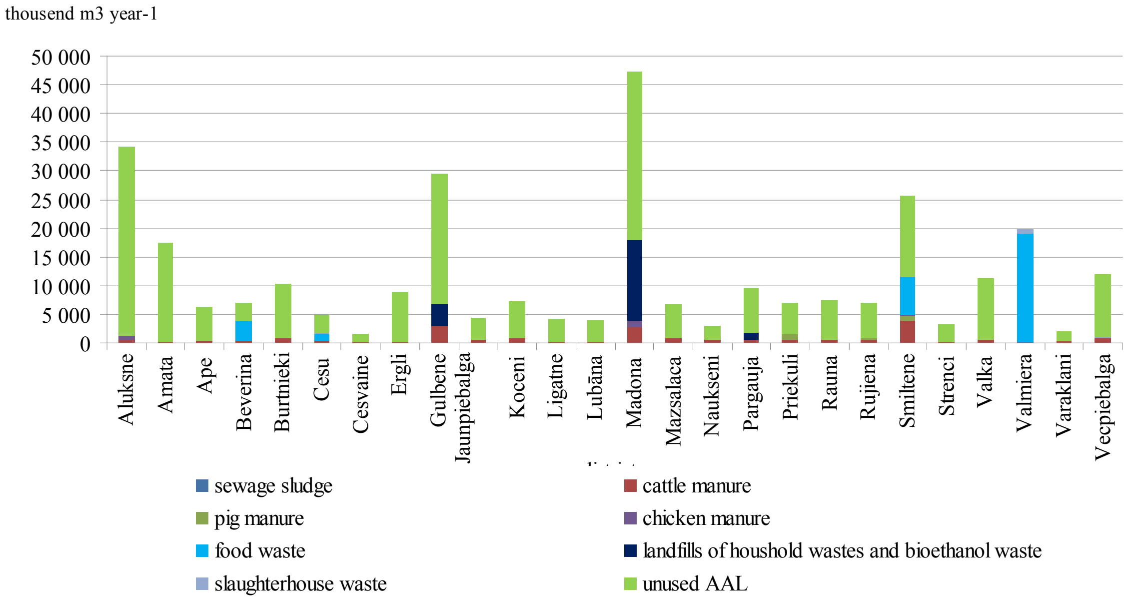
In the work process, considering all potential of raw materials for the biogas production each district can conclude that most of biogas can be obtained in Madona district - 47.4 million m^3 per year. The poultry farm holding company Madona and bioethanol factory Biodegviela Ltd are in Madona district, and there are also quite a lot of cattle farms with more than 101 cattle in a herd. Then following Aluksne district (34.4 million m^3 of biogas per year), with a relatively large unused AAL area (*Database about the unused AAL area, 2010*), Gulbene district (29.5 million m^3 of biogas per year) and Smiltene district (25.7 million m^3 of biogas per year). In Smiltene

Table 2

Food processing industry wastes production and parameters

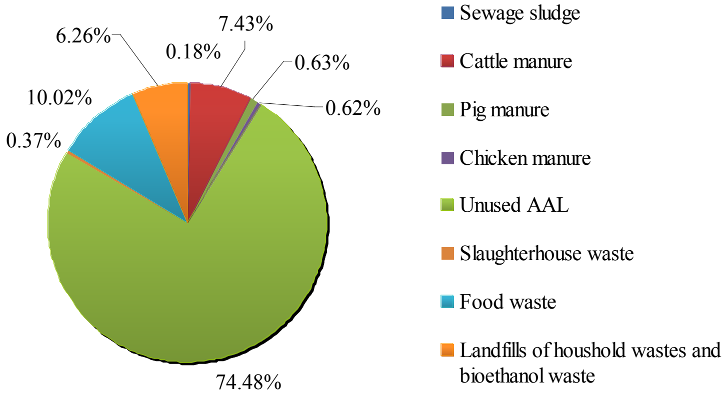
Company	Biomass type	Waste produced, t $year^{-1}$	Dry matter, %	Biogas produced, $m^3\ t_{ODM}^{-1}$
Cesvaines piens	waste water sludge	56.00	0.80	400
	whey	1428.00	0.03	650
Cesu alus	brewer’s grain	6500.00	0.25	750
Lazdonas piensaimnieks	waste water sludge	2.00	0.80	400
	whey	3600.00	0.03	650
Piebalgas alus	brewer’s grain	148.00	0.25	750
Rankas piens	waste water sludge	10.00	0.80	400
	whey	2000.00	0.03	650
Smiltenes piens	waste water, m^3	43725.00	0.38	400
	whey	6000.00	0.03	650
Straupes PKS	waste water sludge	10.00	0.80	400
	whey	3130.00	0.03	650
Valmieras maiznieks	waste water, m^3	840.00	0.38	400
Valmieras piens	waste water, m^3	124000.00	0.38	400
Valmiermuižas alus	brewer’s grain	10.00	0.25	750
Trikatas siers	whey	3762.00	0.03	650
	waste water, m^3	21900.00	0.38	400
MADONA	slaughterhouse	18.00	0.16	625
Sprīdītis	slaughterhouse	51.54	0.16	625
Gaizeni	slaughterhouse	8.75	0.16	625
AIBI	heavy-duty slaughterhouse	2400.00	0.16	625
RUKS	meat processing plant	840.00	0.16	625
Trials	slaughterhouse	8000.00	0.16	625
Kunturi	slaughterhouse	38.40	0.16	625

Source: Database about the pollution license, 2011.



Source: made by the author

Figure 2. **The potential of biogas by districts**



Source: made by the author

Figure 3. **The division of the percentage of the potential of biogas depending on the type of raw materials**

district, animal husbandry and milk processing (Smiltene piens Ltd) are highly developed, there are a lot of cattle farms with more than 100 cattle in a herd, and the pig breeding complex Spriditis Ltd Figure 2 shows the potential of biogas as a whole by district.

The total potential of biogas in Vidzeme region is 304.7 million m^3 of biogas per year. The most of biogas, considering the raw material, can be obtained from unused AAL, where the cultures of intensively growing energy crops (for example, galega - over 225 million m^3 of biogas per year in Vidzeme region) are sown. In percentage this represents 74.5% of the biogas potential of the estimated quantity. Considering the heat capacity it can also be concluded that 1.33 TWh of energy can be gained from the cultures of intensively growing energy crops per year, and the summary of heat capacity of biogas is 1.8 TWh of energy per year (Table 3.).

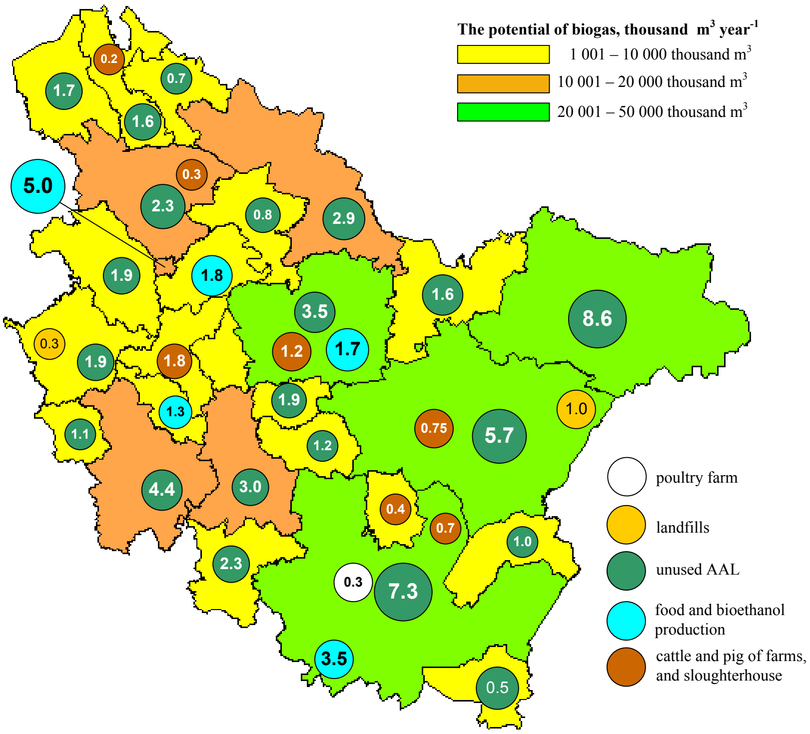
The calculation of energy output from a cubic meter of biogas is 5.0-7.5 kWh of heat capacity can be obtained, depending on the proportion of methane (1 m^3 methane gives about 10 kWh), or an average of 6 kWh m^{-3} or 21.6 MJ m^{-3}. It would produce electricity energy, have been burning 1 m^3 of biogas, 1.5-3 kWh_{el} m^{-3}, or an average 2.2 kWh_{el} m^{-3}. It would produce heat energy of 3-4.5 kWh_{tr} m^{-3}, or an average 4 kWh_{tr} m^{-3}. (*A. Kalnins, 2009.*).

In the work process, after obtaining the potential results of biogas and possible heat capacity of biogas, we can calculate the potential of electrical power of the

Table 3

The summary potential of biomass, biogas and heat capacity of biogas dependence from the types of raw materials

Biomass type	Biomass, t year^{-1}	Potential of biogas, thaus.m^3 year^{-1}	Heat capacity of biogas, kWh m^{-3}	Summary heat capacity of biogas, MWh
Sewage sludge	1 613.16	547.46	6.2	3 394.26
Cattle manure	627 181.50	22 653.80	5.5	124 595.88
Pig manure	29 565.00	1 906.94	6.0	11 441.66
Chicken manure	21 497.74	1 891.80	6.5	12 296.71
Unused AAL	670 251.20	226 966.32	5.9	1 339 101.29
Slaughterhouse waste	11 318.29	1 135.67	5.5	6 246.18
Food waste	-	30 548.22	5.8	189 073.11
Landfills of household wastes and bioethanol waste		19 072.50	5.5	109 415.00
Summary	1 361 426.89	304 722.71		1 795 564.08



Source: made by the author

Figure 4. **Biogas cogeneration plant potentially installed electrical power MW by districts and types of raw materials**

biogas cogeneration plants in each district. Figure 4 shows the results of the calculation.

Conclusions

The total potential of biogas in Vidzeme region is 304.7 million m^3 of biogas per year. The most of biogas, considering the raw material, can be obtained from unused AAL, where sows the cultures of intensively growing energy crops, for example, galega - over 225 million m^3 of biogas per year in Vidzeme region. In percentage this represents 74.5% of the biogas potential of the estimated quantity.

In the work process was concluded that the most biogas can get Madona district – 47.4 million m^3 per year. Because there are many cattle farms, where more than 101 cattle, bioethanol plant "Biodegviela Ltd" with biogas cogeneration plant capacity 2 MW, as well as the poultry farm "Madona" with 228 thousand chickens. The fellow Aluksne district – 34.4 million m^3 of biogas per year, where is the most unused AAL area – about 11 thousand hectares, Gulbene and Smiltene districts – respectively 29.5 and 25.7 million m^3 of biogas per year.

The summary heat capacity of biogas which can be obtained in the Vidzeme`s region is 1.8 TWh, respectively, the amount of electricity which can be produced in a biogas cogeneration plants during a year is 0.7 TWh_{el} and the amount of heat energy 1.1 TWh_{th}.

The largest electrical power of biogas cogeneration plant can be installed in Madona district – 12 MW, The follow Aluksne district with 8.6 MW and Gulbene district – 7.5 MW

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Acknowledgement

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THE INVESTIGATION OF BIOGAS POTENTIAL IN THE PIERIGA REGION

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Abstract
The potential of biogas and available energy have been calculated alone all of Latvia in general until now. The specific character of each region of Latvia was not excluded. In this article many successful biogas plants sites in Pieriga region have been inspected, where biogas is combusted in cogeneration plants producing electricity and heat simultaneously. The biogas potential was also calculated in Pieriga region, where it was produced from domestic animal (cattle, pigs and chicken) manure, as well as the unused agricultural available land (AAL) area, the waste water treatment of biological plants of the largest cities, the largest landfills of solid household waste in the region and food processing industry waste. The majority of the total biogas potential makes around 341 million m^3 of biogas per year in Pieriga region and is derived from the unused AAL area – 216.6 million m^3 of biogas per year. On average, the biogas potential in each the district of Pieriga region makes around 12 million m^3 of biogas per year. The calculated amount of electricity that could be produced by using biogas is around 750 GWh per year.
Key words: biogas production, animal manure, unused agricultural available land.

Introduction

The estimated draft law in Latvia on the renewable energy provides that in 2020 the local renewable energy sources, such as sun, wind, wood and biogas, are allocated a significant proportion (40%) of primary energy consumed in the energy market in Latvia. Therefore, first, the estimated potential of renewable energy, which can be obtained in the conditions of Latvia, has to be examined. Unlike other energy sources, biogas is less dependent on weather conditions and it can be envisaged both in-season, and more distant future, with no special adjustment of the present results. Until now, the potential of biogas has been studied throughout Latvia, to ignore counties and raw material types.

The Pieriga region is characterized with the fact that the average of the unused agricultural lands as a proportion of the total agricultural land is quite remarkable 26%. In this case, a significant potential of biogas in Pieriga region will can be obtained using the culture of intensively growing energy crops, such as eastern galega, canary seed, perennial lupine or tall fescue. In addition, to this potential source of biogas food processing plant wastes and cattle manure may also be added.

Till the end of autumn 2011 five biogas cogeneration plants were operating in Pieriga region:

- waste water treatment plant “Daugavgriva” (2 MW) in Riga;
- waste deposit area “Getlini” (5 MW) in Stopini district;
- Katvaru municipality housekeeping Jaundzelves (0.5 MW) in Limbazu district;
- Sidgunda bio Ltd. (1.6 MW) in Malpis district;
- Bioservis Ltd. (2 MW) in Limbazu district.

In the near future it is expected that two biogas cogeneration plants will start work: Energo Listene Ltd. (1 MW) in Listene municipality of the Tukuma district and Baltic Pork Ltd.. in Sigulda district.

Materials and Methods

When calculating the potential of biogas, the following were taken into account: cattle, pig and poultry manure, food processing industrial waste, the waste water treatment biological plants in the largest cities, the largest landfills of solid household waste in the region, and unused agricultural available land (AAL) area. Technical parameters have been considering at the potential of biogas in calculation, are given in table 1.

The domestic animal housings occupied by more than 101 cattle, 1 001 pig and 15 001 chicken were taken into account.

The number of cattle in the districts of the Pieriga region is mostly balanced: 1 800 cattle on average in a district. The majority of cattle is in Tukuma district – 10 543 cattle, in Ogre district – 6 661 cattle, and in Limbazi district – 6 205 cattle.

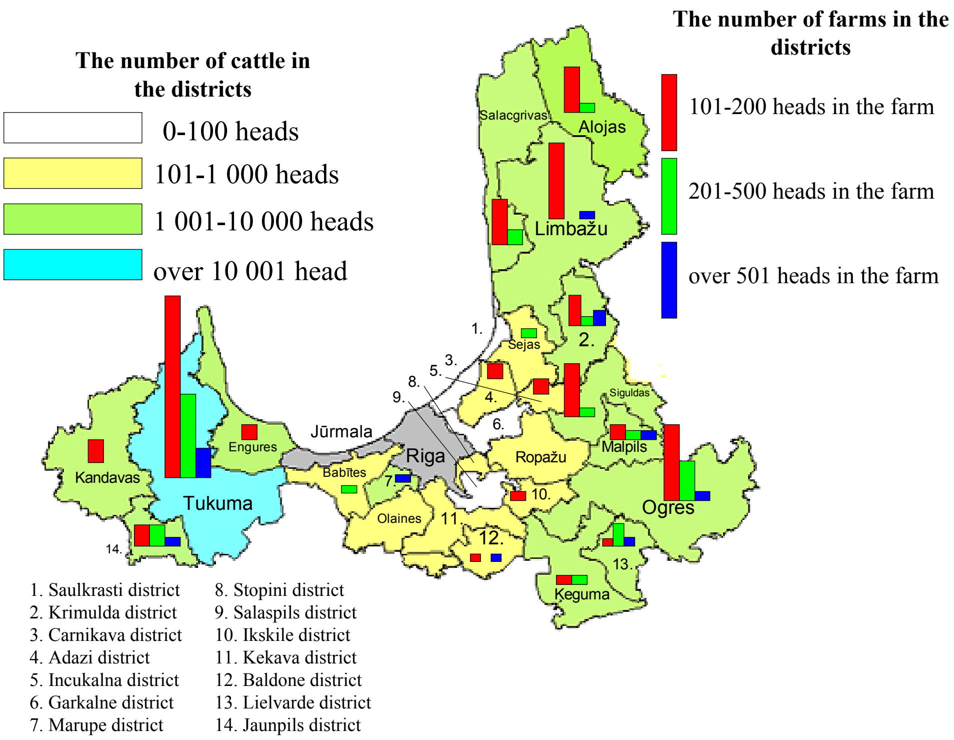
Considering the cattle farms where there are more than 101 cattle, the most such farms are in Tukuma district 29 (19 farms with 101-200 cattle, 7 farms with 201-500 cattle, and three farms with more than 501 cattle), then Limbazi district follows with 14 farms (13, 1, 0) and Ogre district with 13 farms (8, 4, 1). Overall, in Pieriga region there are 78 farms with up to 200 heads in a herd, 27 farms with up to 500 heads in a herd, and 11 farms where there are more than 501 head in

Table 1

Animal manures and wastes production and parameters

Biomass type	Manure or waste produced from one animal, t year^{-1}	Dry matter, %	Organic dry matter, %	Biogas produced, m^3 t$_{ODM}^{-1}$
Cow manure	16.80	14	86	300
Pig manure	1.64	15	86	500
Chicken manure	0.06	22	80	500
Unused AAL	9.00		70	540
Waste water	0.015*			400

** - organic matter from one person*



Source: Database about the number of domestic animals and farms, 2011.

Figure 1. **Number of cattle and farms in the districts of the Pieriga region**

a herd (*Database about the number of domestic animals and farms, 2011.*). Figure 1 shows the concentration of cattle and the number of cattle farms in the districts.

Table 2 summarized the largest food producers from which the gathered waste biogas is potentially obtainable.

The unused AAL area to sows with culture of intensively growing energy crops, for example, galega, the acquired quantity of biogas can be calculated using the following expression:

$$V_B = L \cdot M_{OS} \cdot k_d \cdot v_b \qquad (1)$$

where

V_B – the amount of obtainable biogas from the energy crops culture m^3;

L – unused AAL area, ha;

M_{os} – the obtainable amount of organic solids from the unit of unused AAL area, t ha^{-1} (M_{os} = 8 t ha^{-1});

k_d – the rate of organic matter of biomass conversion,

K_d – 0.7;

v_b – biogas yield from a ton of organic dry matter in the anaerobic process, m^3 t$_{ODM}^{-1}$.

Table 2

Food processing industry wastes production and parameters

Company	Biomass type	Waste produced, t year^{-1}	Dry matter, %	Biogas produced, $m^3\ t_{ODM}^{-1}$
Kekava **	slaughterhouse	658.0	0.16	625
Baltic Pork **	slaughterhouse	70.0	0.16	625
Ulbroka ***	slaughterhouse	10.5	0.16	625
Marno *	slaughterhouse	60.0	0.16	625
MVA *	slaughterhouse	62.8	0.16	625
Rīgas Miesnieks *	slaughterhouse	60.0	0.16	625
Forevers *	slaughterhouse	450.0	0.16	625
Adazu cipsi ****	potato parings	560.00	0.21	610
Aldaris *	brewer's grain	11 521.00	0.25	750
Alojas Sterkelsen ****	potato alburnum	2 660.56	0.24	610
	whey	8 535.60	0.05	650
Limbazu piens *	waste water, m^3	58 690.00	0.38	400
	whey	44.80	0.03	650
Rīgas piensaimnieks *	waste water, m^3	378 562.40	0.38	400
Tukuma piens ****	waste water, m^3	33 580.00	0.38	400
	whey	3 036.00	0.03	650
Jaunpils pienotava ****	whey	3 795.00	0.03	650

Source: Database about the pollution license, 2011.

The amount of biogas produced from sewage sludge can be calculated by the expression:

$$V_B = n_i \cdot k_a \cdot m_i \cdot v_b \cdot k_d \qquad (2)$$

where

- V_B – the obtainable amount of biogas from sewage sludge, m^3;
- n_i – population in locality;
- k_a – coefficient, which indicates the proportion of the population apartments (houses) connected to the biological treatment plants;
- m_i – the amount of organic dry matter in sludge produced by a person per year, kg year^{-1} (m_i = 15 kg year^{-1});
- v_b – biogas yield from a ton of organic dry matter in the anaerobic process, $m^3\ t_{VSd}^{-1}$;
- k_i – the rate of organic matter of biomass conversion,
- K_i – 0.7.

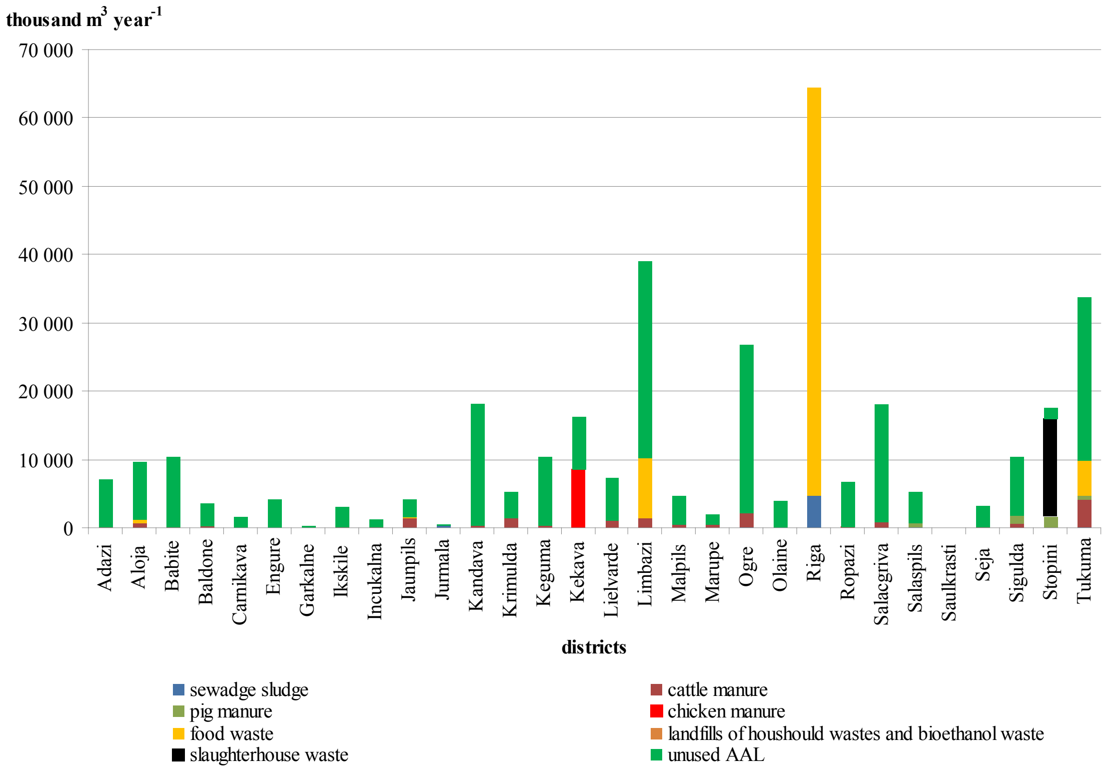
Results and Discussion

In the work process, considering all potential of raw materials for the biogas production each district can conclude that most of biogas can be obtained in Riga – 64.5 million m^3 per year. This is explained by the development of food industry, the largest gain of biogas can to be in "Riga piensaimnieks Ltd.". The following is Limbazi district – 52.6 million m^3 of biogas per year there is the milk processing plant "Limbazu piens Ltd.", Tukuma district - 48 million m^3 of biogas per year. Highly developed animal husbandry and milk processing (Tukums piens Ltd.) is in Tukuma district, as well as there are quite a lot of cattle farms with more than 101 cattle in a herd and the pig-breeding complex "Nica 1 Ltd.". Figure 2 shows the potential of biogas on the whole by districts.

The total potential of biogas in Pieriga region is 341.1 million m^3 of biogas per year. The most of biogas, considering the raw material, can be obtained from unused AAL, where cultures of intensively growing energy crops (for example, galega - over 216 million m3 of biogas per year in Pieriga region) are sown. In percentage this represents 63.5% of the biogas potential of the estimated quantity. Considering the heat capacity it can also be concluded that 1.3 TWh of energy can be gained from the culture of intensively growing energy crops per year, and the summary of heat capacity of biogas is 2.0 TWh of energy per year (see: Table 3).

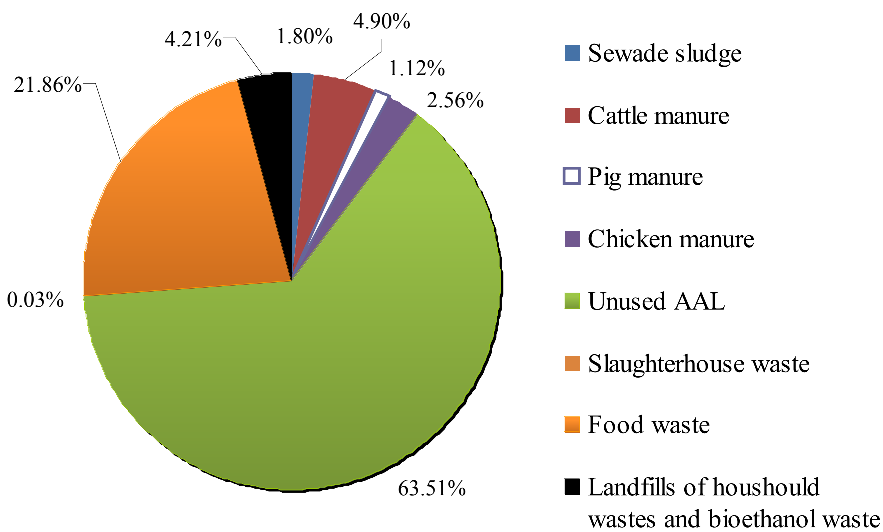
The calculation of energy output from a cubic meter of biogas is 5.0-7.5 kWh of heat capacity can be obtained, depending on the proportion of methane (1 m³ methane gives about 10 kWh), or an average of 6 kWh m^{-3} or 21.6 MJ m^{-3}. It would produce electricity energy, have been burning 1 m³ of biogas, 1.5-3 kWh$_{el}$ m^{-3}, or an average 2.2 kWh$_{el}$ m^{-3}. It would produce heat energy of 3-4.5 kWh$_{tr}$ m^{-3}, or an average 4 kWh$_{tr}$ m^{-3}. (*A. Kalnins, 2009.*).

After obtaining the potential of biogas and heat capacity of biogas can be calculated the potential of electrical power of the biogas cogeneration plants in each district. Figure 4 shows the results of the calculation.



Source: made by the author

Figure 2. **The potential of biogas by districts**



Source: made by the author

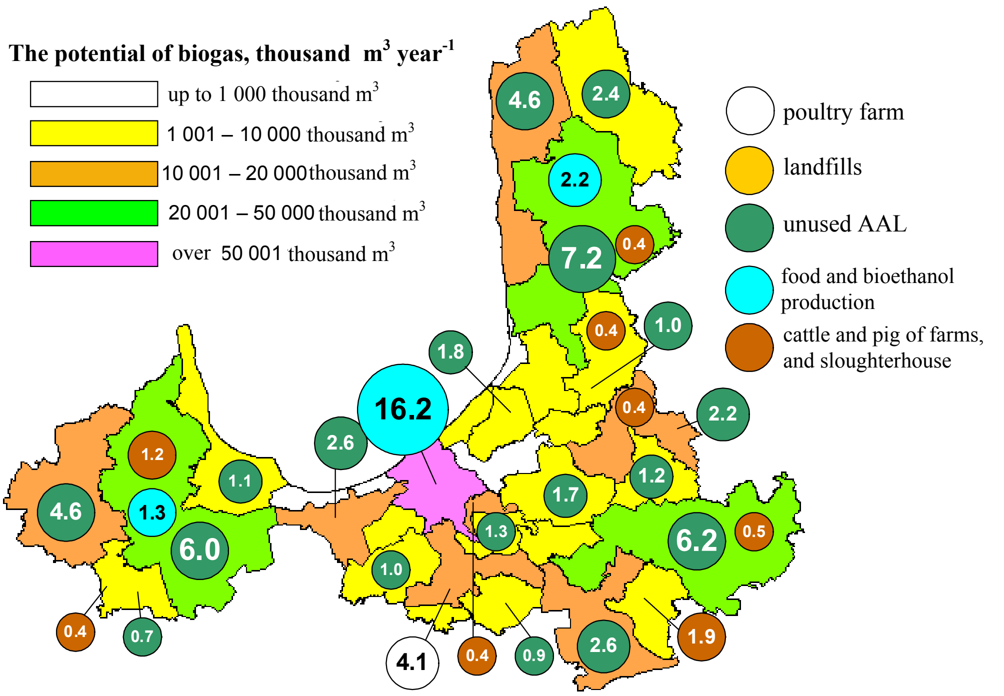
Figure 3. **The division of the percentage of the potential of biogas depending on the type of raw materials**

Table 3

The summary potential of biomass, biogas, and heat capacity of biogas depending on the type of raw materials

Biomass type	Biomass, t year^{-1}	Potential of biogas, thousand m^3 year^{-1}	Heat capacity of biogas, kWh m^{-3}	Summary heat capacity of biogas, MWh
Sewage sludge	14 219.30	6 142.74	6.2	38 084.96
Cattle manure	462 990.00	16 723.20	5.5	91 977.59
Pig manure	59 227.25	3 821.19	6.0	22 927.14
Chicken manure	17 494.45	8 746.92	6.5	56 854.98
Unused AAL	573 156.00	216 652.97	5.9	1 278 252.51
Slaughterhouse waste	1 371.30	92.13	5.5	506.72
Food waste		74 590.64	5.8	460 817.43
Landfills of household wastes and bioethanol waste		14 374.74	5.0	71 873.70
Summary	1 128 458.30	341 144.52		2 021 295.03

Source: made by the author



Source: made by the author

Figure 4. **Biogas cogeneration plants potentially installed electrical power MW by districts and type of raw materials.**

Conclusions

The total potential of biogas in Pieriga region is 341.1 million m^3 of biogas per year. The most of biogas, considering the raw material, can be obtained from unused AAL, where to sows the culture of intensively growing energy crops, for example, galega - over 216 million m^3 of biogas per year in Pieriga region. In percentage this represents 63.5% of the biogas potential of the estimated quantity.

In the work process was concluded that the most biogas can obtained in Riga – 64.5 million m^3 of biogas per year, because there are explained by the development of food industry, the largest gain of biogas can to be in "Riga piensaimnieks Ltd." – 57.5 million m^3 per year. The fellow Limbazi district – 39 million m^3 of biogas per year - there is the milk processing plant "Limbazu piens Ltd.", and Tukuma district – 33.8 million m^3 of biogas per year. Highly developed animal husbandry and milk processing (Tukums piens Ltd.) is in Tukuma district, as well as there are quite a lot of cattle farms, with more than 101 cattle in a herd, and the pig-breeding complex "Nica 1 Ltd.".

The summary heat capacity of biogas, which can be obtained in the Pieriga`s region is 2 TWh, respectively, the amount of electricity which can be produced in a biogas cogeneration plants is during a year 0.78 TWh_{el} and the amount of heat energy 1.22 TWh_{th}.

The largest electrical power of biogas cogeneration plant can be installed in Riga – 16.2 MW. The follow Limbazi district with 9.8 MW and Tukuma district – 8.5 MW.

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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·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·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

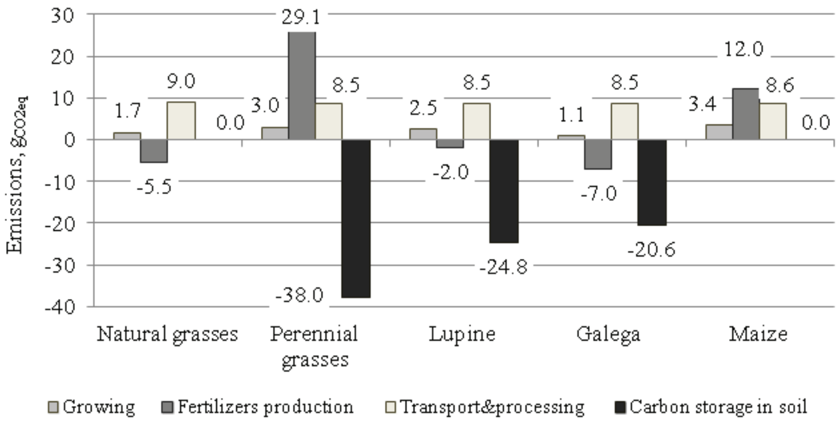

Figure 1. **GHG emissions from energy plants growing, transport&processing and carbon storage in a soil**

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.

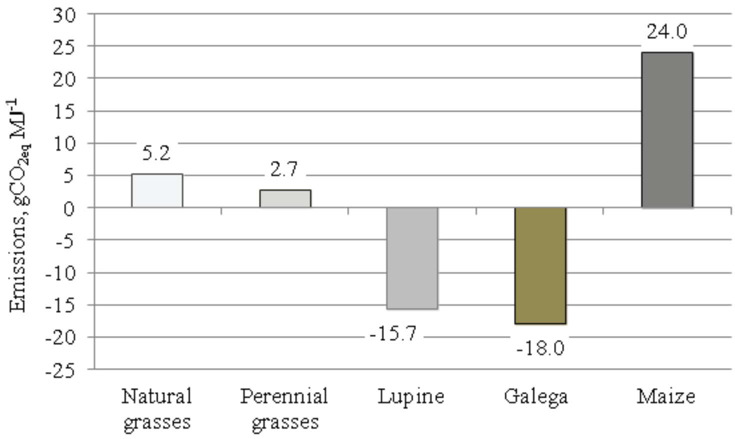

Figure 2. **Total GHG emissions from energy plants usage for energy production**

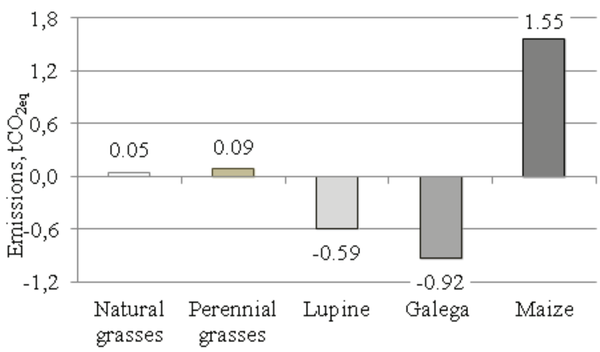

Figure 3. **GHG emissions from energy plants usage for energy production per 1 ha area in year**

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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CUTTING PROPERTIES OF ARRANGED STALK BIOMASS

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Abstract
In Latvia, approximately 14.6% of unfarmed agricultural land can be used for herbaceous energy crop growing. Herbaceous energy crops would be the main basis for solid biofuel production in agricultural ecosystem in future. There is possibility to utilize for bioenergy production natural biomass of common reeds (*Phragmites Australis*) overgrowing shorelines of Latvian more than 2000 lakes. Common reed stalk material ultimate tensile strength average value was stated 330 ± 29 N mm^{-2}. This value testifies that common reeds are the strongest material between other energy crop stalk materials. The main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production is shredding. Therefore common reed stalks were used for cutting experiments. The main hypothesis for cutter design is that cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum.
In experiments was used common reed bundles harvested with Seiga harvester in Pape lake. The experimental bundle cutting mechanism was equipped with a round-shaped counter knife, but the single stalk cutting mechanism was equipped with six different shaped cutting knives. The energy consumption was obtained by integrating force - displacement diagrams. Cutting energy per mass unit dependence on the length of fraction size was calculated. Specific shear cutting energy for a single common reed stalk was determined within $(0.011 \div 0.015)\cdot10^{-6}$ J m^{-2}. Common reed bundle specific cutting energy was determined within $(0.02 \div 0.09)\cdot10^{-6}$ J m^{-2}. The weighted average value was $0.06\cdot10^{-6}$ J m^{-2}. Specific cutting energy for reed bundle cutting significantly exceeded the single stalk specific cutting energy, therefore cutting in thin layers is recommended.
Key words: herbaceous energy crops, common reed bundle cutting.

Introduction

Latvia has target (Directive 2009/28/EC, 2009) in 2020 for renewable energy resources to be 40% in gross final consumption of energy. Common reeds (*Phragmites Australis*), as a natural energy crop material, in Latvia can be found in wetlands and on the shores of rivers, lakes and the Baltic Sea. Mainly they grow on shorelines of Latvian lakes. Therefore herbaceous energy crop growing on these lands can provide sustainable farming practice. There is possibility to utilize for bioenergy production natural biomass of common reeds, overgrowing shorelines of Latvian more than 2000 lakes. The main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production is shredding. Naturally herbaceous biomass is a material of low density (≈ 60 kg m^{-3}) and not favorable for transportation on long distances. Shredding can increase bulk density to 100 ÷ 200 kg m^{-3}.

The purpose of research was to determine cutting properties of common reeds, arranged in bundles. Shredding is the main conditioning operation before preparation of herbaceous biomass compositions for solid biofuel production. According it cutting properties of common reed bundles has to be investigated in order to find the minimum energy consumption for shredding. The main hypothesis for cutter design is that cutting method has to be used with minimum of energy consumption by reducing frictional forces to a minimum. Different mechanisms of cutting knives have to be investigated for energy consumption evaluation. The objective of this study is to determine common reed stalk and bundles cutting properties and energy efficiency of different cutting methods. Different cutting methods have to be investigated for energy consumption evaluation and shredder cutter mechanism design.

Materials and Methods

In cutting experiments were used common reed stalks with moisture of 10% and stalk material density of 615 kg m^{-3}. In single stalk cutting experiments were used stalks with diameter 7 mm, thickness of wall – 0.5 mm. In common reed bundle cutting experiments were used bundles with height within 1.2 – 1.5 m, upper diameter – 0.08 m, lower diameter – 0.18 m. Bundles were harvested with Seiga harvester in the Pape lake.

In single stalk cutting experiments, energy consumption for stalk cutting was investigated using the Zwick materials testing machine TC-FR2.5TN. D09 with 0.4% force resolution, 0,1 µm displacement resolution and the maximal force for testing - 2,5 kN. For shear cutting parameter determination, an original cutting device was designed. The cutting device was equipped with six different cutting knives (Fig. 1) where bevel angle for all cutting knives was 45°, but the blade angle was within 0° - 25°. The blade angle more than 25° was not used because it is

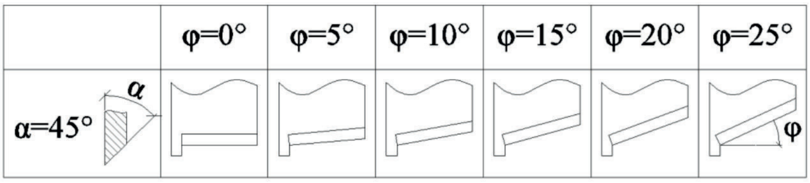

Figure 1. **Cutting knives with different blade angle**

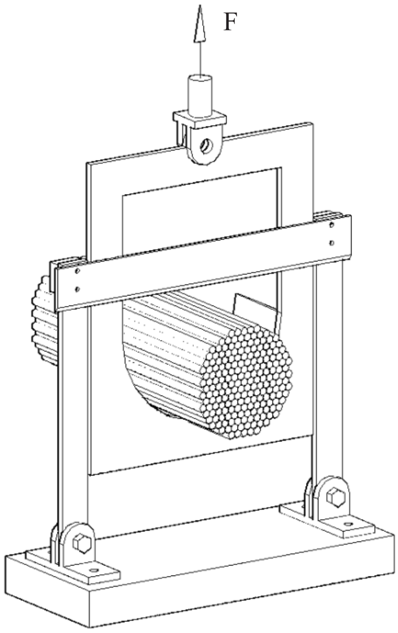

Figure 2. **Bundle cutting mechanism**

a nip angle for polished steel and common reed stalk materials.

Displacement and stress data for single stalk cutting experiments were collected and processed by using Zwick software program TestXpert V9.01. The energy consumption was obtained by integrating force – displacement diagram. Specific cutting energy consumption was investigated for all types of cutting knives.

In reed bundle cutting mechanism (Fig. 2) one cutting knife with blade angle of 0° and bevel angle of 45° was used. Common reed bundle was cut first from the upper end, the length of cut stalk particles was 0.1 m. The weight of cut stalk material was calculated as difference of bundle weight before and after cutting. The displacement and cutting force sensor data was used for cutting energy determination. The displacement and cutting force sensor data from Pico data logger were processed by Microsoft Excel program. MathCAD program was used for cutting energy per mass unit calculation.

In all experiments the common reed stalks or reed bundles were orientated perpendicularly to the cutting knife. The displacement speed of cutting knives was 0.15 m min^{-1}. Single stalks cut area was calculated from data obtained from direct measurement with sliding calliper (accuracy ± 0.01 mm).

Specific cutting energy was calculated:

$$E_{SC} = \frac{E_C}{A} \tag{1}$$

where

E_{SC} – specific cutting energy, J m^{-2};
E_C – cutting energy, J;
A – stalks cut area, m^{-2}.

Cutting energy per mass unit was calculated (Srivastava, et.al., 1993):

$$E_{CM} = \frac{E_{SC}}{L \cdot \rho} \tag{2}$$

where

E_{CM} – specific cutting energy per mass unit, J kg^{-1};
L – length of stalk cut, m;
ρ – stalk material density, kg m^{-3}.

Specific cutting energy was calculated:

$$E_{SC} = E_{CM} \cdot L \cdot \rho = \frac{E_C}{m} \cdot L \cdot \rho \qquad (3)$$

where

m – cut stalk mass, kg.

Cutting area was calculated:

$$A = \frac{m}{L \cdot \rho} \qquad (4)$$

The average specific cutting energy for common reed bundle cutting was calculated:

$$E_{SC}^{A} = \frac{\Sigma E_C}{\Sigma m} \cdot L \cdot \rho \qquad (5)$$

where:

E_{SC}^{A} – average specific cutting energy for common reed bundle, J m-2;

ΣE_C – total cutting energy consumption for all experiments, J;

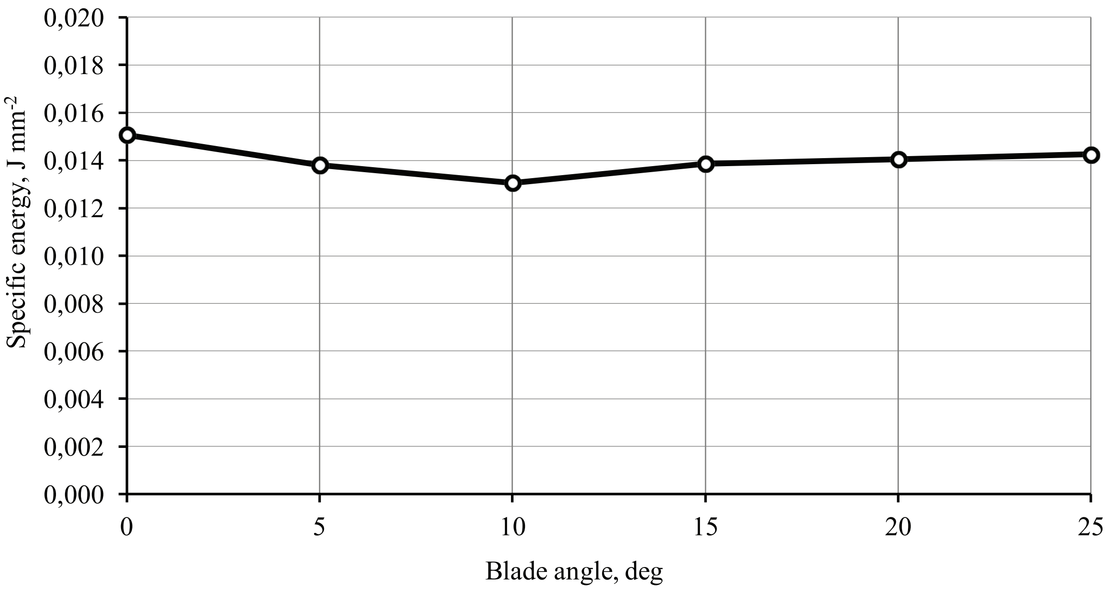

Figure 3. **Reed stalks material specific cutting energy dependence on knife bevel angle**

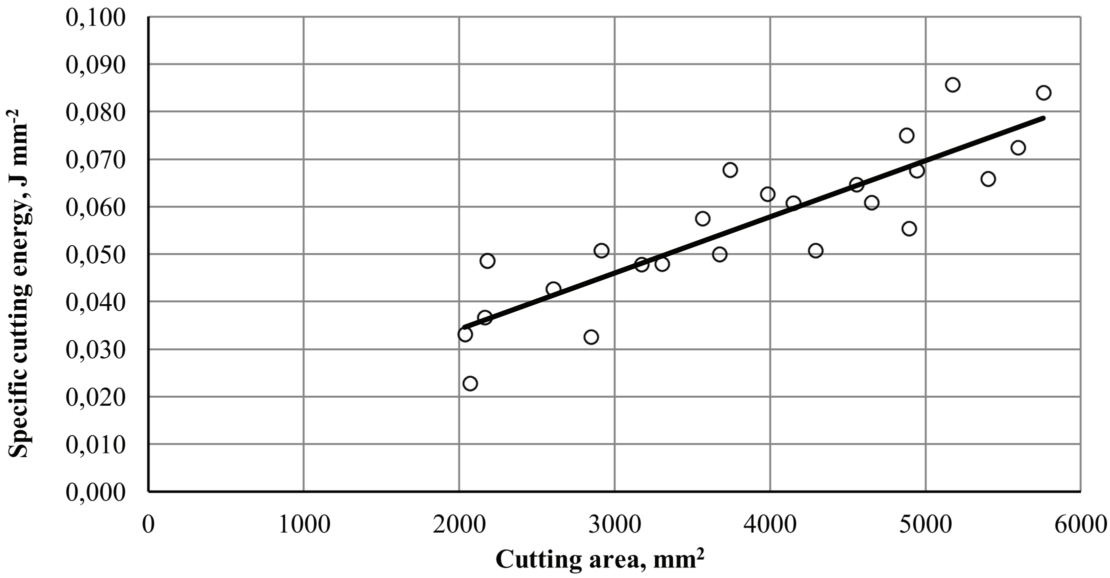

Figure 4. **Specific cutting energy dependence on cutting area**

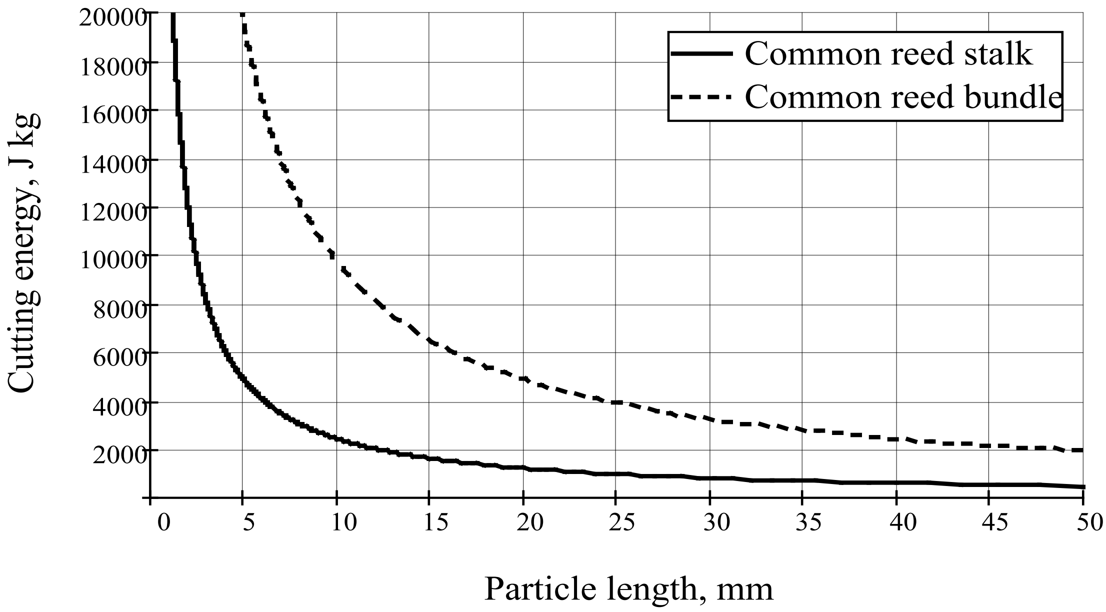

Figure 5. **Cutting energy per mass unit dependence on particle length**

Σm – total cut stalk mass in all experiments, kg.

Results and Discussion

Common reed single stalk material specific cutting energy values are shown in Figure 3. Average specific cutting energy for single common reeds was within $(0.013 \div 0.015)\cdot10^{-6}$ J m^{-2} when cutting knives with different bevel angles were used. There was no significant difference between the specific cutting energy values for different blade angles, therefore maximal value $0.015\cdot10^{-6}$ J m^{-2} can be used for calculations.

Common reed bundle specific cutting energy values are shown in Figure 4. Common reed bundle specific cutting energy was within $(0.02 \div 0.09)\cdot10^{-6}$ J m^{-2}, and the weighted average value was $0.06\cdot10^{-6}$ J m^{-2}, if the cutting knife with the bevel angle of 45° and blade angle of 0° was used.

Specific cutting energy for reed bundle cutting significantly exceeded single stalk cutting specific energy, therefore cutting in thin layers is recommended. The point of intersection of trend line extension with ordinate axis (Fig. 4) was near the value of single common reed stalk specific cutting energy ($0.015\cdot10^{-6}$ J m^{-2}). These results prove that common reed bundles specific cutting energy linearly depends on the cross section of the bundle.

Specific cutting energy per mass unit (Fig. 5) was determined on the basis of stalk material density of 615 kg m^{-3}, specific cutting energy value for single stalk - $0.015\cdot10^{-6}$ J m^{-2}, and average for bundle - $0.06\cdot10^{-6}$ J m^{-2}.

Specific cutting energy per mass unit for reed bundles significantly exceeded the single stalk specific cutting energy per mass unit; therefore it is more preferable to harvest common reed bundles with smaller dimensions if common reeds are used for solid fuel production.

Conclusions

Specific cutting energy for single common reed stalk cutting is within $(0.011 \div 0{,}015)\cdot10^{-6}$ J·m^{-2}, if cutting blades with bevel angle 45° and blade angles within 0° - 25° are used.

There is no significant difference between specific cutting energy values for different blade angles, therefore maximal value $0.015\cdot10^{-6}$ J m^{-2} can be used for calculations.

Common reed bundle specific cutting energy is within $(0.02 \div 0.09)\cdot10^{-6}$ J m^{-2}, the weighted average value is $0.06\cdot10^{-6}$ J m^{-2}, if the cutting knife with bevel angle 45° and blade angle 0° is used.

The experiment results prove that common reed bundles specific cutting energy linearly depends on the cross section of the bundle.

Specific cutting energy per mass unit for reed bundles significantly exceeds the single stalk specific cutting energy per mass unit; therefore it is more preferable to harvest common reed bundles with smaller dimensions if common reeds are used for solid fuel production.

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PRELIMINARY DATA ON THE PRODUCTIVITY OF STUMP LIFTING HEAD MCR-500

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Abstract
The first published studies on stump extraction for bioenergy in Latvia are dated with second half of the 19th century. In the 3rd decade of the 20th century, stump extraction was identified as one of the most prospective and challenging tasks of forest sector to secure sustainable deliveries of solid biofuel. In that time, stump extraction using explosives was considered to be a conventional forestry technology. Now we are returning to the same challenges; however, mechanical power is used instead of explosives to pull and to crash stumps.
MCR-500 is the first prototype of combined stump extraction and mounding head for a caterpillar excavator produced in Latvia by joining forces of the LSFRI Silava and engineering company Orvi SIA. The device is supposed to be used for extraction of stumps with a diameter up to 50 cm in coniferous and deciduous tree stands. Additional benefit of the device is ability to prepare soil by making mounds for the following forest regeneration. The article summarizes results of productivity trials of stump extraction and preparation of soil using the MCR-500 head. In total, 3.5 ha were extracted during the studies. The harvested amount of stumps was estimated using biomass equations; therefore, it might be corrected in further forwarding and comminution studies when an actual amount of biomass is estimated. Average stock of extractable biomass (stumps and coarse roots) in the experimental sites was 28 tons ha^{-1}. Productivity of stump extraction was 2.4...3.4 tons per efficient hour (2.5 tons in case of optimal rate of scarification of soil). Consumption of efficient time for scarification of soil is 3.4...4.3 hours per ha. Figures of productivity of stump extraction are comparable with the ones obtained with similar stump extraction heads. Scarification of soil with stump lifting head consumes twice more time than conventional trenching; however, in wet sites, productivity figures become closer making the excavator competitive.
Key words: stump extraction, excavator, productivity, biofuel.

Introduction

In spite stump extraction for bioenergy seems to be advanced and new technology arose some decades ago, the first scientific evidence of stump extraction research are dated back to the 19th century when stump harvesting was already well known and commonly used for solid biofuel production and just like now researchers studied an effect of stump extraction on productivity of forest stands (Bode, 1840). After Latvia become a free country in the beginning of the 20th century, questions on independence from external energy sources arose with a new power and researchers returned to stump extraction and the relevant forest regeneration issues. Just like now, opposite viewpoints were declared. For instance, O. Ceichner proposed that blowing up stumps is facilitating leaching of nutrients and erosion of soil. He recommended not to practise blowing up stumps in the state forests (Ceichners, 1929). At the same time, he and other researchers agreed that stump extraction is facilitating natural regeneration of pine stands and does not affect in any harmful way trees of the next generation (Vasiļevskis, 2007). K. Lange was one of the most active advocates of stump extraction. He declared that leaving of stumps in clear-felling areas for decaying is wrong, particularly in less forested regions suffering from lack of firewood (Lange, 1925). Before the World War Two, a production of firewood from stumps reached 7...30 thousand m3 annually. In 1939, the Forest Administration recommended to utilize all clear-felling areas for stump extraction. At that time the most conventional method for stump extraction was blowing up; however, mechanical extraction using special heavers including the ones invented and produced in Latvia became more and more common. Average productivity of stump extraction using heavers was 1,6...2 m3 per day (Vasiļevskis, 2007).

After retrieval of independence, stump extraction and stump biomass for long time did not reach the field of interests of forest practitioners and energy companies because other resources of woody biomass (firewood, residues from sawmills and harvesting remaining) were available in abundant amounts and nearly for free. Significant changes in attitude to stump biofuel happened at the beginning of the 21st century due to constantly growing demand for solid biofuel in local and foreign markets. Since 2006, stump biofuel is produced mainly in forest road construction and utilized as admixture to wood chips from harvesting remnants or sawmill residues. Stump biofuel is not sold as a separate assortment in Latvia yet (Andis Lazdiņš, 2006). The first studies of productivity of mechanized stump extraction in clear-felling areas were implemented in 2006 in cooperation with the Forest Research Institute of Sweden Skogforsk (M. Thor et al., 2008). A caterpillar excavator with a specialized stump lifting head produced by CBI was used in these studies. Average productivity of stump extraction was 10,4 m3 per hour; respectively, 40 times higher than 60 years ago (Andis Lazdiņš and Magnus Thor, 2009); however, these studies did not solve the issues relevant to forest regeneration after stump extraction because the device used was not suited for soil preparation during stump extraction. Additional scarification increases costs of forest regeneration and makes stump extraction unprofitable.

To contribute to improved forest regeneration after stump extraction, the Latvia State Forest Research Institute Silava in cooperation with the engineering and production company Orvi SIA in 2011 invented a new stump lifting device MCR-500, which was aimed to combine the best available knowledge in stump extraction and mounding as a soil scarification method. The device can lift and split stumps and prepare soil with an auxiliary plough producing mounds (initially, an area of mound is 0.25 m^2, in the second prototype – 0.36 m^2). The experimental trials with the first prototype of this device were established in 2011 nearby Riga in Daugava Forestry of the Riga city forest management company Rīgas meži Ltd. Different parameters, like productivity of harvesting and forwarding of stumps, quality of site preparation, and measures relevant to forest regeneration are studied in these trials.

Materials and methods

Stump extraction was done during September, 2011 in Riga forests of Daugava Forestry in 3 forest stands harvested in clear-felling in the winter of 2010/2011. Stand characteristics are provided in Table 1. Stands are sorted in the same sequence they were extracted. Further in the text, codes of the stands consisting of the compartment and block number are used. The stands were split into 4 (forest blocks No. 176 and 98) and 2 (forest block No. 104) experimental sites. Half of the stands were treated in a conventional way (site preparation with a forest trencher) and remaining half – with a stump extraction device doing simultaneous stump extraction and site preparation. All stumps with a diameter more than 20 cm in areas supposed for the stump extraction were measured (determining an average height, diameter, presence of decay and tree species) and marked with visible signs noting the number of the stump.

The stump extraction device MCR-500 was mounted on a New Holland 215B excavator (Figure 1) during the studies. The operator did not have previous

Table 1

Experimental stands

State forest district	State forestry	Forest block	Compartment	Area, ha	Dominant tree species	Stand type	Harvested roundwood volume, m^3
Riga	Ogre	176	18	2.3	Pine	*Myrtilloso-sphagnosa*	949
Riga	Ogre	98	4	3.8	Birch	*Hylocomiosa*	1542
Riga	Ogre	104	9	1.5	Spruce	*Myrtillosa mel.*	293

Source: calculation of the authors

Source: made by the authors

Figure 1. **Stump extraction head MCR-500 on an excavator New Holland 215B**

experience; therefore, the first site (176-18) can be considered as a training place.

All operations were recorded using special tools (Allegro field computer with SDI program). Time consumption was measured separately for every stump. During the time studies, an engineer recording time consumption wrote down the number of treated stump for each record; therefore, it is possible to estimate time consumed for a particular stump with a known height, diameter and species.

The working time was split into eleven operations: (1) turning of tower; (2) driving in a stand; (3) reaching a stump, relevant manipulations with the crane; (4) catching of stump; (5) lifting of stump; (6) splitting of stump; (7) shaking to get rid of soil; (8) dropping to get rid of soil or split a stump; (9) scarification – site preparation; (10) other unexpected operations; (11) other operations not relevant to efficient working time (phone conversations etc.).

The engineer doing time studies also noted the number of mounds prepared between each stump lifting operation. Everything except other operations not relevant to efficient working time was considered as the efficient time.

The five working rules implemented in the last two stands was:

1. extraction of stumps being in a diameter range of 20...50 cm, except spruce, which did not have an upper limit of the diameter;
2. stumps of black alder, ash and other relatively rare tree species important for biological diversity should not be extracted;
3. no stumps should be harvested on strip-roads to avoid problems during forwarding, an exception is dry sites with excellent soil bearing capacity;
4. extracted stumps should be piled in narrow rows alongside the existing strip-roads, an excavator should not use strip-roads during extraction;
5. soil should be prepared in front of the excavator below the stump storage areas and behind the excavator in the rest of area.

Fuel consumption was determined by measurement of refilled volumes of diesel. Average fuel consumption was applied to all trials.

Extracted biomass was estimated using biomass expansion equations published by different researchers in Nordic countries (Marklund, 1988; Repola, Ojansuu, and Kukkola; Hakkila, 1975). Above- and below-ground parts of stumps, coarse roots (diameter above 5 cm) and fine roots (diameter below 5 cm) were considered in calculations. The biomass expansion equations of the dominant tree species in the stand are assumed for rare tree species like aspen and black alder. Average density of wood was considered from the greenhouse gas inventory guidelines (Penman, 2003). The aboveground part of stumps was treated in formulas as cylinder. Fine roots are excluded from measurement of extracted volume (extractable biomass), assuming that they will stay in the ground.

Results and discussion

Total area extracted during trials was 3.5 ha; the total number of extracted stumps – 1235 (74 % of total number of stumps in all trials); an average diameter of extracted stump – 33 cm; biomass extracted during trials according to the biomass equations applied in the study – 96.8 tons (64 % of total extractable biomass); average dry weight of a single stump – 78 kg; the number of prepared mounds – 1997 (Table 2).

In calculation to area units (per ha), the average number of extracted stumps was 353, extracted biomass – 27.7 tons ha^{-1}, all extractable stumps (except stumps marked as too small, too big, belonging to species important for biological diversity as well as stumps of strip-roads) – 43.1 tons ha^{-1}, the average number of prepared mounds – 571 per ha^{-1} (from 315 to 1496), total efficient time – 9.5 hours ha^{-1} including 7.6 hours for stump extraction and 1.9 hours for mounding (Table 3). Notably that in the last stand (104-9), time consumption for soil scarification was 3.3 hours (more by 73 %), but the number of produced mounds – greater than average by 162 %. Similarly, productivity of stump extraction in the last stand was by 20 % higher than in the first stand. Difference between the first and second stand was not so significant. It means that an operator gets used to the working method within 4 days (time consumed for the first 2 stands). However, the average size of stumps in

Table 2

Characteristics of experimental trials and stumps

Object	Area, ha	Extracted stumps	Share of extracted stumps	Average diameter of extracted stumps, cm	Biomass of extracted stumps, kg	Share of extractable biomass	Biomass of average stumps, kg	Prepared mounds
176-18	1.1	415	90%	30	25197	72%	61	346
98-4	1.7	550	71%	36	54108	66%	98	604
104-9	0.7	269	63%	32	17479	53%	65	1047

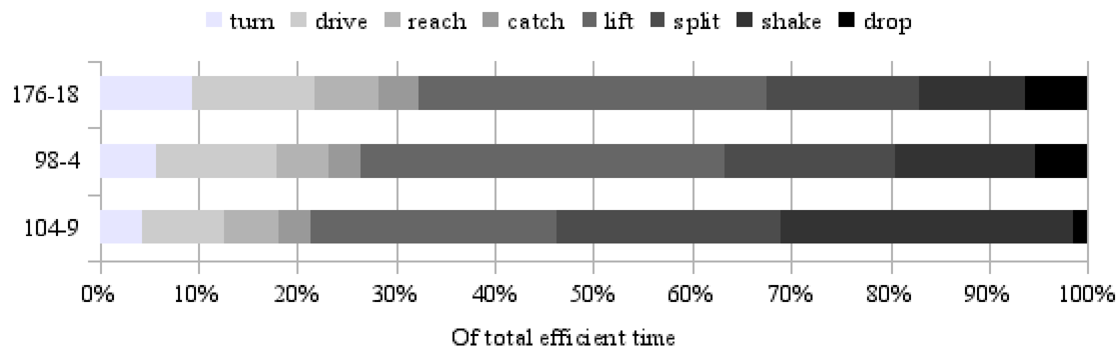
Source: calculation of the authors

Table 3

Productivity figures recalculated to area units

Object	Number of extracted stumps, per ha	Extractable biomass, kg ha^{-1}		Number of prepared mounds per ha^{-1}	Efficient time, hours ha^{-1}			
		extracted stumps	all stumps		total	for stump processing	for mounding	for soil preparation
176-18	377	22907	31774	315	9.4	8.3	1.0	3.0
98-4	324	31828	48511	355	10.4	8.5	1.9	3.4
104-9	384	24970	47242	1496	9.8	6.6	3.3	4.3

Source: calculation of the authors



Source: calculation of the authors

Figure 2. **Share of different operations**

the second stand (98-4) was considerably bigger than in other stands; therefore, decrease in productivity may be explained by unfavourable working conditions. The second stand also characterizes by larger share of birch stumps (27 % of total extracted biomass in comparison with 16 % on average).

If not measuring operations relevant to stump extraction only, average time for soil preparation would be 3.4 hours ha^{-1}. In the last stand, where the number of prepared mounds was optimal or even too big, scarification took 4.3 hours. The disc trenching in a control plot in the same stand took 1.8 hours ha^{-1}. Assuming that stump extraction does not take place and the excavator prepares 2200 mounds ha^{-1} having the same productivity as in the trials, it would take 6.4 hours ha^{-1} to prepare soil. The disc trenchers have 2...3 times higher prime cost of production; therefore, the service price for the both technologies is comparable.

The share of different operations in different stands is shown in Figure 2. The chart clearly shows that in every next stand an operator spends less time on turning, driving in a stand, lifting of stumps; and spends more time on splitting and shaking. In contrast to the first stand, where the operator tried to drop stumps to get rid of soil, at the end of the study he mostly used shaking. This switch in the working method led to considerable visual improvement of quality of extracted biomass; although this method is not healthy both to machine and to the operator. The problem with dropping arose from too slow movement of the splitting knife of the MCR-500 because of technical issue with pressure in hydraulic system – during all the study, the splitting knife got only 65 % of the necessary pressure. In case of shaking, the operator does not have to open the splitting knife several times per stump in contrast to dropping and in contrast to recommendations, the operator completely abandoned dropping as a cleaning method at the end of the study. However, in normal working conditions we would recommend to stick on multiple dropping instead of shaking.

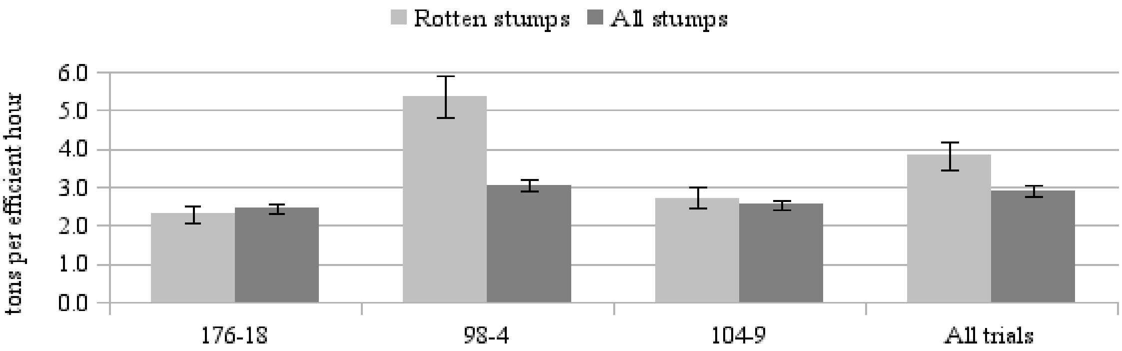
The number of multiple operations was studies to understand if it is reasonable to try to extract several closely located stumps at once or it does not have an effect on productivity. Summarizing results in 14 % of extraction cycles, the operator lifted more than 1 stump, which contributed to 21 % of extracted biomass. Average biomass of stumps extracted in multiple operations was considerably bigger (by 63 %) than of stumps extracted in single operations (Table 4). Time consumption per stump in the multiple and single operations does not differ, but in calculation to biomass, the difference becomes significant – in multiple operations time consumption

Table 4

Extraction of several stumps

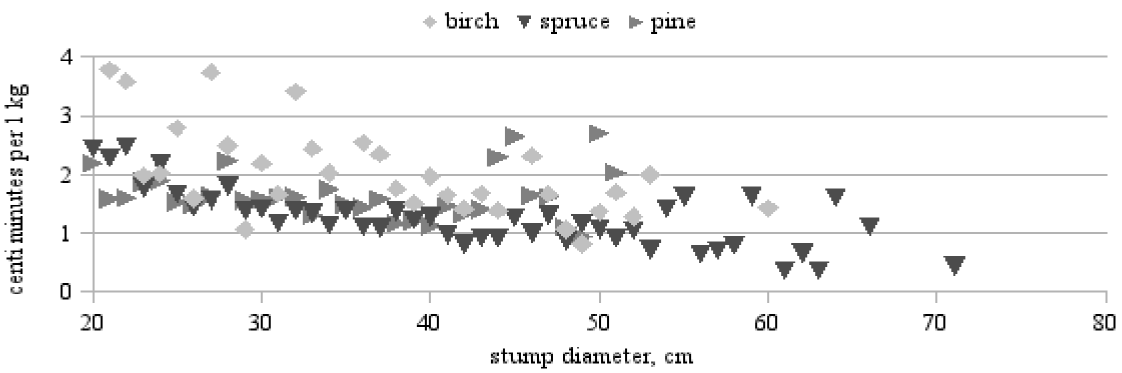
Several stumps in one operation	Percentage of total extracted stumps	Percentage of total biomass	Average biomass of stump, kg	Average time per stump, sec.	Average time, sec. kg^{-1}
1 stump	85.9%	78.9%	70	62	0.89
2 stumps	12.4%	19.2%	117	60	0.51
3 stumps	0.9%	0.8%	62	58	0.94
4 stumps	0.3%	0.2%	41	27	0.66
5 stumps	0.4%	1.0%	200	87	0.44

Source: calculation of the authors



Source: calculation of the authors

Figure 3. **Productivity depending on presence of decay**



Source: calculation of the authors

Figure 4. **Productivity depending on diameter of stump**

per kg is by 41 % smaller (0.53 in comparison with 0.89 sec kg^{-1} in single operations). Obtained results demonstrated that the operator does not have to keep off multiple operations, especially if 2 stumps can be lifted at once.

Another important point to study is the impact of root rot on productivity of stump extraction. The average number of stumps having visual presence of root rot damages was 17 %; in the first trial (176-18), it was only 2 %, in the second an third – 23 %. Harvestable biomass of rotten stumps was 18 %, on average. Figure 3 shows that there is significant difference in productivity working with rotten and healthy stumps – the last takes considerably more time on average, but especially in the second stand.

Evaluation of time consumption for the stump extraction depending on a diameter of stump shows that the diameter significantly affects productivity (Figure 4). For birches, productivity continues to grow for stumps reaching a diameter of approximately 45 cm; then productivity remains relatively constant. For pines, the productivity slightly increases for stumps reaching approximately 43 cm in diameter. For spruces, slight increase in productivity continues even if stumps are more than 60 cm in diameter.

Conclusions

The average extracted stump biomass in the trials according to the biomass equations was 27.7 tons ha^{-1}, (7.6 % of extracted roundwood expressed in m^3); real figures will be known only after comminution because the equations used are known for underestimation of the biomass. Total efficient time – 9.5 hours ha^{-1} including 7.6 hours for stump extraction and 1.9 hours for mounding.

Training of an inexperienced operator to reach a high level of productivity and quality of soil scarification takes 3...4 days. The most of effect relates to quality of soil preparation.

If the evaluated technology is used only for soil preparation (production of 2200 mounds ha^{-1} having the same productivity as in the trials), scarification would take 6.4 hours ha^{-1}. The disc trenching in a control plot in the same stand took 1.8 hours ha^{-1}; however, the disc trenchers have 2...3 times higher prime costs, which might equalize the service price in practice.

The study results demonstrated that the multiple operations are beneficial, especially if 2 stumps can be lifted at once; therefore, operators should always evaluate ability to extract 2 or more stumps at once.

There is significant difference in productivity when lifting rotten and healthy stumps – rotten stumps are easier for extraction; however, it is hard to predict if the same biomass expansion factors can be applied to healthy and rotten stumps.

The species and size of stumps affect productivity; for birches, productivity grows for stumps reaching 45 cm in diameter, for pines, the productivity slightly increases for stumps reaching 43 cm in diameter, for spruces, productivity grows even if stumps are more than 60 cm in diameter.

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PRELIMINARY RESULTS OF ESTIMATION OF FOREST BIOMASS FOR ENERGY POTENTIALS IN FINAL FELLING USING A SYSTEM ANALYSIS MODEL

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Abstract
Forests in Latvia have the highest potential to increase sustainable deliveries of biomass to secure implementation of the National and the Community targets in reduction of the greenhouse gas (GHG) emissions and increase of the share of renewables in the energy sector. According to the study, the final felling is the most significant source of forest biomass for energy in Latvia being able to provide additionally about 8.6 mill. MWh of primary energy annually (excluding the firewood assortment and potential production losses) without increase of the harvesting rate.
The scope of the study is to adapt results of the productivity studies and harvesting cost calculation models to the biomass production system analysis and to estimate resources of the biomass in the final felling on the base of the current harvesting rate and production costs. Harvesting slash (tops and branches) and stumps are considered in the study, taking into account the impact of technical (losses) and site specific limitations of the biomass production. Additionally, machinery and labour necessary for the full scale production as well as the GHG emissions from additional fuel consumption and amounts and characteristics of wood ash to be managed after the full scale implementation were evaluated.
The study demonstrates that the technological potential of biomass for energy in final felling, keeping the harvesting rate at the level of 10 mill. m^3 annually, is 2.1 mill. tons, including firewood. The full scale production would require about 1.3 mill. of working hours, at least 400 units of different machinery and more than 1000 of qualified operators. The prime cost of production at full load of the machinery and the full scale production would be about LVL 45 mill.; however, this figure is higher now due to growth of fuel cost. The additional emissions would be equal to about 36 thousand tons of carbon.
Key words: forest biomass, final felling, bioenergy, system analysis.

Introduction

Forest biomass is already making a substantial contribution to meeting global energy demand. This contribution can be expanded significantly in the future, providing greenhouse gas savings and other environmental benefits, as well as improving trade balances, providing opportunities for social and economic development in rural areas, and improving the management of resources and wastes (Bauen, Berndes, Junginger, et al., 2009).

Bioenergy could sustainably contribute between a quarter and a third of global primary energy supply in 2050. It is the only renewable source that can replace fossil fuels in all energy markets – in the production of heat, electricity, and fuels for transport (Lysen and van Egmond, 2008). However, expansion of bioenergy also poses some challenges. The potential competition for land and for raw material with other biomass uses must be managed. The productivity of forest biomass needs to be increased by improved forestry practices. Bioenergy must become increasingly competitive with other energy sources. Logistics and infrastructure issues must be addressed to continuously harmonize and to reach maximum synergy of forest management and solid biofuel production (Schmidt, Gass, and Schmid, 2011).

At present, forestry is the main feedstock for the generation of electricity and heat from biomass. Today, biomass supplies some 50 EJ globally, which represents 10 % of global annual primary energy consumption. This is mostly traditional biomass used for cooking and heating (Bauen, Berndes, Junginger, Londo, and Vuille, 2009). There is significant potential to expand biomass use by tapping the large volumes of unused harvesting residues, stumps and small trees not used in other industries. Based on this diverse range of feedstock, the technical potential for biomass, including forest resources, is estimated in the literature to be possibly as high as 1500 EJ annually by 2050, although most biomass supply scenarios that take into account sustainability constraints, indicate an annual potential of 200...500 EJ annually. Forestry and agricultural residues (including municipal solid waste) would provide between 50 and 150 EJ annually (Schmidt, Gass, and Schmid, 2011; de Wit and Faaij, 2010).

Projected world primary energy demand by 2050 is expected to be in the range of 600...1000 EJ (compared with about 500 EJ in 2008). Scenarios looking at the penetration of different low carbon energy sources indicate that future demand for bioenergy could be up to 250 EJ annually. Growth in the use of biomass resources in the mid-term period to 2030 will depend on different demand and supply side factors. Strong renewable energy targets being set at regional and national level (e.g. the European Renewable Energy Directive) will lead to a significant increase in demand (de Wit and Faaij, 2010). This demand is likely to be met through increased use of forest resources. Estimates of the potential increase in production do vary widely, just like prognosis for potential deliveries of solid biofuel. For example, the biomass potential from residues and energy crops in the EU to 2030 is estimated to range between 4.4 and 24 EJ (de Wit and Faaij, 2010).

The scope of the study is to evaluate availability and cost of forest biomass resources for bioenergy needs in final felling in Latvia using a system analysis approach for the machine cost and productivity estimates. Final felling stock and distribution by stand types and dominant tree species is borrowed from harvesting reports in 2007 by the State Forest Service, because production in this year was not affected by the economic crisis.

Materials and methods

The study involves estimates of the biomass resources in final felling including harvesting residues, stumps and firewood, but excluding wood processing residues, which are already fully utilized and, therefore, will not contribute in future to increase of solid biofuel deliveries from forest. Felling sites are merged into groups according to growing conditions. All forest types are considered in estimation of potential resources; however, technically available resources of harvesting residues are estimated only for mezotrophic and fertile stand types with good soil bearing capacity (*Vacciniosa, Myrtillosa, Hylocomiosa, Oxalidosa, Aegipodiosa, Myrtillosa mel. and Mercurialosa mel.*). Technically available resources of stumps are not estimated in *Cladinoso-callunosa*. Potential resources of forest biomass in final felling are estimated by multiplication of harvested stock and biomass expansion factors (Table 1) obtained in studies implemented in Latvia in cooperation with the Joint stock company "Latvia State Forests" (Lazdāns, Lazdiņš, and Graudums, 2005; Thor, Von Hofsten, Lundström, et al., 2006; Lazdāns and

Table 1

Relation between roundwood and biomass for energy

Type of solid biofuel	Spruce dominant stands	Deciduous trees stands	Pine dominant stands
Harvesting residues, tons per m^{-3} of roundwood		20 %	15 %
Stumps and coarse roots, tons per m^{-3} of roundwood	20 %	20 %	20 %

Source: calculation of the authors

Table 2

Input data used for system analysis

Type of resource	Harvesting	Forwarding	Road transport to temporary terminal	Comminution	Loading	Road transport to end use place
Time consumption in scheduled working hours, tons per hour						
Firewood	13.1	8.6				16
Harvesting residues		5.7		7		3.3
Stumps	5.2	4.3	18.8	12	50	4.2
Prime cost of working hour, LVL per hour excluding administration and profit						
Firewood	47.3	30.7				23.8
Harvesting residues		30.7		58.3		23.8
Stumps	37.9	28.8	25.1	88.7	25.9	23.1
GHG emissions in the production and delivery process, kg C per ton of biomass						
Firewood	0.4	0.8				0.7
Harvesting residues		1.1		3.6		3.3
Stumps	1.9	1.8	3.4	6.7	0.2	3

Source: calculation of the authors

Table 3

Assumptions for solid biofuel quality

Parameter	Firewood		Harvesting residues and stumps	
	Coniferous stands	**Deciduous stands**	**Coniferous stands**	**Deciduous stands**
Ash content, %	0.3 %	0.3 %	2 %	2 %
Higher heat value, kWh kg^{-1}	5.69	5.61	5.83	5.56
Lower heat value, kWh kg^{-1}	5.33	5.28	5.56	5.28

Source: Thor, Iwarsson-Wide, Von Hofsten, Nordén, et al., 2008; Thor, von Hofsten, Lundström, Lazdāns, and Lazdiņš, 2006

Lazdiņš, 2006; Thor, Berndt, Von Hofsten, Lazdāns, et al., 2008).

The share of technologically available resources (for firewood 5 %, for harvesting residues and for stumps 40 % of the technically available resources) are estimated using research data and expert judgements proposed in the studies implemented in Latvia earlier (Thor, von Hofsten, Lundström, Lazdāns, and Lazdiņš 2006; Thor, Berndt, von Hofsten, Lazdāns, et al. 2008; Lazdāns and Lazdiņš 2006).

Production costs, labour intensity, utilization of machinery and emissions of greenhouses gases (GHG) during the production and delivery are calculated using a tool for system analysis of production costs derived from Swedish model Flis (von Hofsten 2005). Input data for the model are taken from the studies implemented in Latvia earlier (Thor, Von Hofsten, Lundström, Lazdāns, and Lazdiņš 2006; Thor, Berndt, von Hofsten, Lazdāns, et al. 2008; Lazdiņš, Zariņš, Daugaviete, et al. 2007). Fuel costs and salaries are updated according to a nowadays situation. An average distance for fuel delivery is assumed 40 km, an average forwarding distance – 0.3 km, an average number of relocations of forest machinery – 60, an average load of chip truck – 70 m3. Carbon content in biofuel and fossil fuel for calculations of the GHG emissions is assumed 67 kg m-3 (LV – loose volume) and 0.87 kg kg^{-1} (0.72 kg L^{-1}). The assumed bulk density of wood chips is 5 (Andis Lazdiņš, Daugaviete, Bārdulis, et al. 2008). The summary of input data used for system analysis is provided in Table 2.

Assumptions on heat value and ash content of forest biofuel (Table 3) are taken from relevant studies (Thor, Iwarsson-Wide, Von Hofsten, Nordén, et al., 2008; Thor, von Hofsten, Lundström, Lazdāns, and Lazdiņš, 2006) and biofuel standards (Alakangas, 2011). The same values are used for stumps and harvesting residues.

Results and discussion

The total potential biofuel resources in final felling according to the harvesting stock distribution in 2007 is 3 412.7 ktons, including 2 142.8 ktons of technologically available resources annually (Table 4). Nearly half of the potential could be provided by stump extraction and 29 % – harvesting residues (Figure 1). Both resources are not sufficiently utilized nowadays. The biggest technologically available harvesting stock of solid biofuel per area unit (26.7 tons ha^{-1}) is also characteristic for stumps.

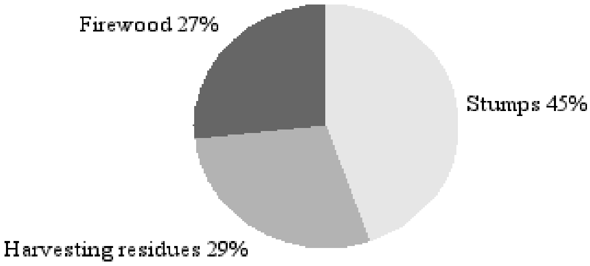
Full scale production of solid biofuel in final felling would fully utilize about 400 units of different kind of machinery, starting from excavators for stump extraction and finalizing with chip trucks (Table 5). The most of the investments relates to stump extraction, where 53 excavators can be fully utilized during the whole year in 2 shifts. This would require about LVL 7 mill. investments. In real world conditions, the machinery will not be utilized to a full extent; therefore, the necessary amount of the machinery can be safely increased by 30...40 %. Full scale production of solid biofuel in final felling would require about 1200 employees working on forest machines (Table 3), excluding administrative and service staff, which is necessary to manage the process. Like in the case with the machines, the number of operators can be increased by 30...40 % to get real world figures on necessary staff. The most of the employees will

Table 4

Resources of forest biomass in final felling

Operation	Firewood	Harvesting residues	Stumps	Total
Potential resources, ktons	600.6	1 205.5	1 606.6	**3 412.7**
Technically accessible resources, ktons	600.6	1 023.1	1 597.2	**3 320.9**
Technologically available resources, ktons	570.6	613.9	958.3	**2 142.8**
Technologically available resources, tons ha^{-1}	5.3	21.5	26.7	**-**

Source: calculation of the authors



Source: calculation of the authors

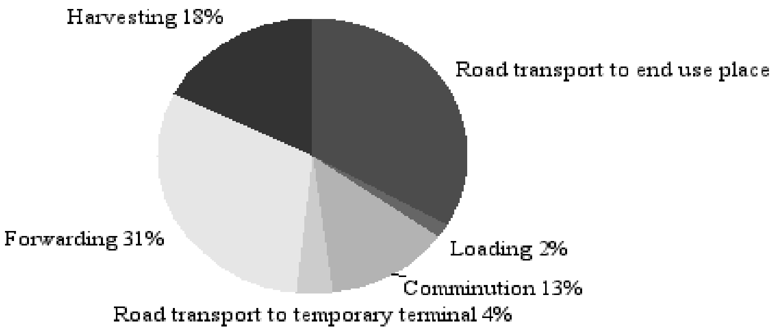
Figure 1. **Distribution of technologically available resources**

Table 5

Necessary labour and machinery resources

Operation	Firewood	Harvesting residues	Stumps	Total
Machinery				
Harvesting	17		53	**70**
Forwarding	22	35	64	**121**
Road transport to temporary terminal			15	**15**
Comminution		27	25	**52**
Loading			6	**6**
Road transport to end use place	10	55	67	**132**
Labour				
Harvesting	50		160	**210**
Forwarding	65	106	193	**364**
Road transport to temporary terminal			45	**45**
Comminution		81	74	**155**
Loading			19	**19**
Road transport to end use place	31	164	202	**397**
Total number of operators	**146**	**351**	**693**	**1190**

Source: calculation of the authors



Source: calculation of the authors

Figure 2 **Distribution of employees by technological process**

be necessary for the stump production and delivery chain. No new machinery and employees are necessary for the firewood production because this resource is already fully utilized; however, there are huge areas of low valued forest biomass belonging to private persons and companies, where firewood is the most convenient output.

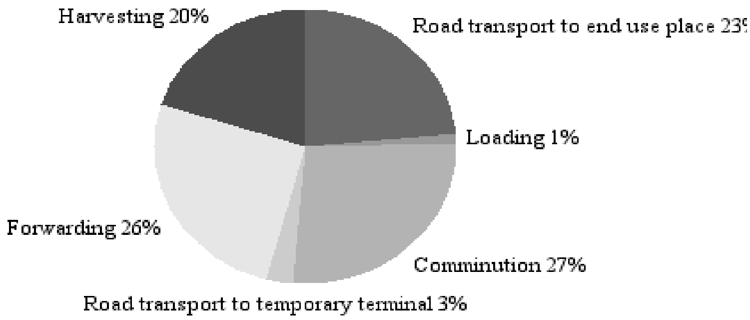
The estimation of the prime cost of the solid biofuel production is very approximate because the system analysis implemented for the study considers full

Table 6

Prime cost of production, thousand LVL, a year

Operations	Firewood	Harvesting residues	Stumps	Total
Harvesting	2 067.9		6 988.7	**9 056.6**
Forwarding	2 038.4	3 295.2	6 397.1	**11 730.7**
Road transport to temporary terminal			1 276.2	**1 276.2**
Comminution		5 116.5	7 086.8	**12 203.3**
Loading			496.2	**496.2**
Road transport to end use place	848.9	4 462.1	5 326.3	**10 637.3**
Total	**4 955.3**	**12 873.8**	**27 571.3**	**45 400.4**

Source: calculation of the authors



Source: calculation of the authors

Figure 3 **Distribution of prime cost by technological process**

Table 7

Emissions of carbon in the technological processes

Operations	Firewood	Harvesting residues	Stumps	Total
Harvesting	0.3		3.1	**3.4**
Forwarding	0.5	1.2	2.8	**4.4**
Road transport to temporary terminal			5.4	**5.4**
Comminution and loading		3.7	11.1	**14.7**
Road transport to end use place	0.4	3.4	4.9	**8.6**
Total	**1.1**	**8.2**	**27.1**	**36.4**

Source: calculation of the authors

utilization of the machines; however, it is hard to predict real figures, especially because some technologies are not yet implemented at an industrial scale, for instance, stump extraction. Administration and service costs, which are not evaluated in the system analysis, may be very important part of the market price of biofuel and it's dependant on organizational structure (size of companies, contracting principles) and comfort level of the industry – if the prices are high, administrative costs are rising, as soon as prices drops, administrative costs follow. The system analysis implemented in this study shows that prime costs of biofuel production in final felling if working to a full extent would be LVL 45 mill. annually (Table 6), and 62 % of the cost relates to the stump biofuel production. The weighted average prime cost of biofuel in final felling is 24.4 LVL ton^{-1} (4 LVL MWh^{-1}). Stump biofuel has the highest prime cost – 28.8 LVL ton^{-1}.

Total emissions (carbon released by incineration of diesel) during the production and delivery process could reach 36.4 ktons of carbon (C) annually (Table 7). Stump extraction would contribute to 74 % of the emissions. Comminution is the most energy consuming process (39 % of the total emissions); however, all types of transport consume even more (51 % of the total emissions). Average C emissions due to the incineration of fossil fuel are 3.4 % of carbon stored in the delivered solid biofuel or 3.2 kg MWh^{-1}.

Conclusions

According to the system analysis, the total potential solid biofuel resources in final felling in Latvia, based on the harvesting stock data, was 3 412.7 ktons in 2007. Technologically available resources (excluding the resources located on soils with low bearing capacity and losses during the procurement) are 62 % of the potential. The completely unused part of the resources is stumps (45 % of technologically available amount).

Full scale implementation of solid biofuel production in final felling would require about 400 units of different machinery and about 1200 qualified operators for the machines. Taking in account that in real world conditions the machines will not be utilized to a full extent, the necessary amount of the machines and operators would be by 30...40 % higher. The most of the investments and the new labour places relates to stump extraction.

The system analysis implemented in this study shows that prime costs of biofuel production in final felling if working to a full extent would be 45 mill. LVL annually. The most expensive solid biofuel resource in final felling is stumps (62 % of the total cost). The weighted average prime cost of biofuel in final felling is 24.4 LVL ton^{-1} (4 LVL MWh^{-1}). The most of the savings are possible in the comminution and road transport stage.

Total carbon emissions during the production and delivery process in case of full scale production would reach 36.4 ktons annually. Weighted average carbon emissions from the forest machines are equal to 3.4 % of carbon stored in the delivered solid biofuel.

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HEAT OF COMBUSTION OF HEMP AND BRIQUETTES MADE OF HEMP SHIVES

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Abstract
The hemp straw production gives 25 % of fibre and 75% of shives. The research, conducted by the Institute of Natural Fibres & Medicinal Plants in Poznan, proved high energetic value (about 18 MJ kg^{-1}) of shives used for briquettes production, which does not require additional drying. A shives burning process emits less sulphur compounds than the burning of oil fuel or coal, which has a positive impact on the environment.
The yield of hemp straw produces 10–15 tons of biomass from 1 hectare plantation. It is estimated that cultivation of 1 ha of hemp absorbs about 2.5 tons of CO_2, which contributes significantly to lessening of the greenhouse effect.
Key words: hemp, shives, briquettes, energy.

Introduction

It is assumed that the main biomass producer for energy purposes will be agricultural industry. The intention is to have in Poland in 2020 the share of energy acquired from biomass on the level of 15% in the balance of energy obtained from renewable sources, while in 2030 that of 20%. It means that in 2020 we should have in Poland 0.5 million ha of energy plants plantations while in 2030 - 0.8 million ha. Nowadays the acreage in Poland is only ca. 10 thousand ha.

The Economics Department is running intense works on preparation of 'Poland's Power Policy until 2030' document. The paper will in details describe strategic directions of action within the area of Poland's power policy.

Hemps in Poland haven't been called power plants until now nor its cultivation for the purposes is allowed (Act on misuse of drugs of July 29th, 2005 as amended). Only waste products obtained from the process of fibre extraction may be used for bio-energy production. The situation is different in other countries of the European Union where hemps are perceived as power plants and their cultivation for power purposes is allowed. Nowadays in Poland intense works are carried out aiming at allowing hemp cultivation for biomass.

Materials and Methods

The analysis of combustion heat was made for the whole hemp plants and for the hurds (waste product) obtained during extracting fibre from hemp straw.

Before the test, the material for analysis was crushed in a cutting-grinding mill of the mesh diameter at 0.25 mm. The test involved burning a precisely weighed sample in oxygen atmosphere under pressure in a calotrimetric bomb device and measuring the temperature increase inside the

Photo 1. **Hemp plantation**

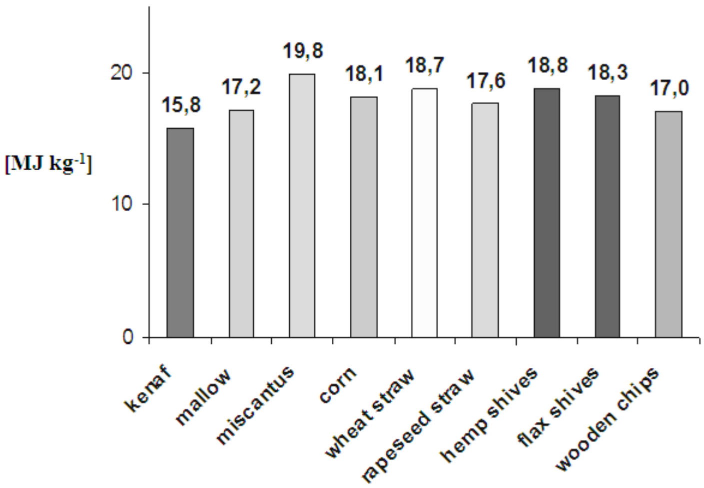

Figure 1. **Heat of combustion of selected vegetable raw materials**

calorimetric container, where the calorimetric bomb is placed.

Results and Discussion

Research run by the Institute of Natural Fibres and Medicinal Plants shows that fibre hemps because of high biomass yield and high heat of combustion amounting to ca. 19 MJ kg^{-1} are perfect for the purposes of bio-energy production. High heat of hemps combustion is confirmed also by other authors in their research, that is 18.8 MJ kg^{-1} (Burczyk H, Kolodziej J. Kowalska M 2008) from 17.5 to 18.8 MJ kg^{-1} for whole plants and even 19.7 MJ kg^{-1} for hemp bunches (Burczyk H., Grabowska L., Kołodziej J., Strybe M. 2008). The heat of combustion for dry straw is from 14 to 15 MJ kg^{-1} (Grzybek A., Gradziuk P., Kowalczyk K. 2001). In literature it is assumed that in terms of power, 1.5 tonne of straw is equal to 1 tonne of hard coal of medium quality (Grzybek A., Gradziuk P., Kowalczyk K. 2001). Straw from 1 hectare of hemp cultivation area corresponds in terms of power to even 11 tonnes of hard coal (Kolodziej J. 2009). It is confirmed by Burczyk (Burczyk H., Kolodziej J., Kowalska M. 2008), who experimentally obtained power yield from one hectare of hemps expressed in tonnes of hard coal on the level from 10.2 to 11.1 t (Burczyk H., Kolodziej J., Kowalska M. 2008). An additional advantage is that they are annual plants cultivated without the necessity of applying chemical means of protection and that leave soil in good culture. Additionally hemps may be cultivated for fibres, used in production of biodegradable composite materials, non-woven fabric and cellulose applied by paper industry and only harls may be used for power purposes (shives making up ca. 70- 75% of plant mass).

Hemps are interesting plants in terms of economy and ecology. In hemp cultivation, there is no need to apply crop protection chemicals, hemps are naturally resistant to diseases, they hamper growth of many weeds, discourage vermin and use nutrients included in soil. Hemp biomass yield is ca. 10 - 15 t ha^{-1} what with high heat of combustion (ca. 19 MJ kg^{-1}) allows to obtain plants power yield amounting to ca. 200 - 260 GJ ha^{-1} (Kolodziej J. 2009). Additionally, hemps, as opposed to other perennial power plants (e.g. energetic willow) may be easily introduced into crop rotation.

Hemps harvested in the full bloom of inflorescence are left on the field until they get dried by air to dry matter (ca. 16% of moisture for the whole plants). The moisture of hemp shives (of harls being wastes after fibre extraction from straw) is ca. 8.5% (Kolodziej J. 2009), while crop straw moisture is 15% and of wooden chips even 40% (Wichrowski R. 1994). In terms of yielding, hemps are inferior to such plants cultivated for energy purposes as kenaf (ca. 24 t ha^{-1}) and miscanthus (ca. 30 t ha^{-1}) (Kozlowski R., Kaniewski R., Mankowski J. 1998). Kenaf heat of combustion is ca. 15,8 MJ kg^{-1} and miscanthus - ca. 19,8 MJ kg^{-1}, but they are plants not very well adapted to our climate or requiring high expenditures for cultivation. They do not compete with hemps, as kenaf and miscanthus plantations are started from seedlings. They are perennial plants, so they are not suitable for cultivation in crop rotation.

The experiments carried out in the Institute of Natural Fibres and Medicinal Plants showed that new hemp types in the trial phase yield on the level amounting to even ca. 22 tonnes of straw from 1 ha of cultivation (Burczyk H., Grabowska L., Kolodziej J. Strybe M. 2008), so they have great potential for biomass production for energy purposes.

Heat of combustion for hemp biomass is comparable with the corn heat of combustion (ca. 18 MJ kg^{-1}). Hemp yields in relation to corn are more stable and in lesser degree depend on atmospheric conditions. Experiments carried out

Photo 2. **Briquettes made of hemp shives**

show that in the years which characterize with less rainfall, hemp energy efficiency was greater than corn energy efficiency. Hemps in comparison to corn characterize with a shorter vegetation period that is why it is easier to include them in the crops rotation. As far as corn is concerned, it is necessary to additionally spend energy for the purposes of drying it, as because it is harvested in autumn it is not possible to dry it on the plantation.

Hemp heat of combustion is greater than *Helianthus tuberosus* heat of combustion (16.5 MJ kg^{-1}) (Grabowska L., Kolodziej J., Burczyk H. 2007) and only slightly lower than miscanthus heat of combustion, which is ca. 19.8 MJ kg^{-1}).

In order to make transportation and storage easier, hemp harls may be subjected to briquetting or pelletization process.

Briquettes and pellets make a fuel obtained by compressing of dry waste materials. No chemical additives are used in the production process. Shives get stuck together as a result of the action of steam and high pressure. The material utilized during shaping of briquettes and pellets is lignin.

Hemp briquettes are characterized by faster loss of mass during combustion, compared with commonly used briquettes made of wood chips. This results from the fact that heat release from hemp briquettes is considerably faster. Measurements carried out on briquettes made of hemp shives have pointed to their considerable heat of combustion that is about 18000 kJ kg^{-1} (in the case of wood: 17000 KJ kg^{-1}). Combustion of shives results in significant reduction in the emission of sulfur compounds that is lower than that observed during combustion of heating oil and coal.

Conclusions

Hemps are the raw materials of multi-directional usage for textile, technical, food and pharmaceutical purposes. Together with the increasing ecological awareness and searching for alternative actions for agricultural industry, hemps were rediscovered as a plant attractive for many branches of economy. Hemps produce yearly a great amount of environmentally friendly biomass which may be used almost 100% in clothes production, technical textile, paper production, non-woven materials production, insulation, construction, composite materials production, hygienic, food, pharmaceutical articles production and for bio-energy.

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REGIONALLY SPECIFIC HARVESTING RESIDUE YIELD AND RECOVERY RATES USED FOR ENERGY POLICY DEVELOPMENT

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Abstract
We assessed the importance of residue yield rate ρ and recovery rate η for forest biomass recovery. Studies indicate that ρ ranges from 20-50% and η from 60-80%. Estimates of available residues for energy use a combination of both factors. By using reported ranges, we obtained estimates of available biomass for given areas that varied by a factor of three. Yet, energy policies are being developed that use single values of these two factors over large geographic areas.
We concluded that the wide range of reported rate values is a function of the combinations of tree form, harvesting systems, and current markets that influence utilization. Thus, more precise estimates of energy from logging residues will require development and use of regionally specific yield and recovery rates. Until rates are developed that are specific for species groups and harvesting systems, conservative values of these rates should be used (ρ=20% and η=60%).
Key words: residue yield rate, recovery rate, biomass.

Introduction

Many factors including concerns about climate change have led many countries to pursue development of renewable energy (Ladanai 2009). The United States (US) is experiencing unprecedented interest in developing renewable energy including that from woody biomass. As an example, the state of North Carolina has set an energy goal to increase renewable electricity production up to 12.5 % by the year 2021, according to Senate Bill 3 (S-3), 2007, The Renewable Energy and Energy Efficiency Portfolio Standard (REPS). (Abt et al. in press, General Assembly of North Carolina Session 2007). Perlack et al. (2005) concluded that biomass in general and especially logging residues from final harvests are expected to play a pivotal role in meeting national renewable energy goals. Unfortunately, the viability of using residues for large-scale energy production is inadequately documented from a sustainability perspective (Gan and Smith 2006). Therefore, studies are needed to determine sustainable levels of residues realistically available for renewable energy.

Estimates of potential available residues require knowing what percentage of total harvested tree volume can be expected to be left on site as logging residues following harvesting (residue yield rate or ρ) and the proportion of logging residues which is typically recovered (current recovery rate or η) (Gan and Smith 2006)). Current recovery rates are affected by available technology, costs, environmental constraints and other factors. Total logging residues (LR) can be calculated by multiplying the amount of total harvested volume, ρ – the residue yield rate and η – the recovery rate of logging residues. LR for this study were calculated from inventory data as reported by the US Forest Service Inventory and Analysis Program (FIA) data (US Department of Agriculture (USDA) Forest Service, 2009). Many studies on available biomass do not discuss ρ and η values while others state their values but do not discuss where those values were obtained.

Logging residues consist of branches, tops above the merchantable stem for traditional forest products, and non-merchantable stems. The amount of logging residues yielded from harvested timber depends on tree form, stand quality, and utilization limits – a function of equipment used and decisions by the logger based on markets. Trees with a decurrent tree form have a weak central leader that eventually produces a rounded tree crown (most hardwood trees: oak, hickory, maple, etc.), whereas excurrent trees have a single and strong central trunk with lateral branches, as in spruce trees (Oliver and Larson 1996). Trees with decurrent growth habit or large branches from sparse stands will have larger values of ρ, whereas dense stands or stands with excurrent species will have lower values. Species with persistent limbs will have higher values of ρ than self-pruning species. Higher utilization standards where logs are utilized by timber industry to a smaller top diameter will have lower values of ρ than with larger top-of-log diameters.

The two principal objectives of this study were to (1) evaluate reported ρ and η and to postulate a reasonable range of values typical for southeastern US forests and harvesting systems, and (2) use these rates to estimate ranges of annually available biomass in North Carolina as a sample region and discuss impacts of the selection of these values on policy development.

Methods

To achieve our objectives we: (1) conducted a meta-analysis to determine influences in archetypal ρ and η; (2) determined which ρ and η are appropriate representatives of the southeastern US; (3) applied ρ and η to the current harvest data to estimate logging residual potential; (4) projected estimates for a 30-year time span with the Sub-Regional Timber Supply (SRTS) model (Abt et al., 2009); and then (5) compared results with policy-based goals and evaluate their reasonableness with respect to two policies – the North Carolina REPS (North Carolina general Assembly 2007) and the Renewable Fuel Standard (RFS) (Project Co-conveners and Steering Committee 2007) goals in North Carolina.

Estimates of ρ and η for the US including the FIA, EU, and an unpublished North Carolina field study data were compared to assess reasonable ρ and η for North Carolina. An extensive literature review was done to summarize and interpret more than 40 studies with a focus on ρ and η. Only studies from the EU and US that discussed both ρ and η and cited the data source for ρ and η were selected.

Data were then sorted and categorized into ρ and η groups for the US and EU based on tree species, region and harvesting technology. Average values of ρ and η were summarized in graphs. Not all ρ and η data were directly comparable because of different research methodologies used. For example, Green and Westbrook et al. (2007) used the approach that defines η as the difference between estimated residues and actually recovered residues. In our approach, however, η is a rate based on actual reported rates, where the residue percentage recovered reflected the real-world logging chance that the logger faced including economic, ecological, political and technological aspects. And indeed, recovery rates may change in time depending on political goals, technical feasibility and associated costs. In many sources, ρ and η were only discussed, but no values were disclosed.

Gan and Smith (2006) calculated an average ρ and η using USDA Forest Service's FIA *Timber Product Output* (*TPO*) database. "Logging residues" data columns were divided by "all removals" columns (growing stock and non-growing stock inclusive); however biomass estimates in the FIA database were minimally supported by empirical data (Roesch et al.). For example, there was only one sample plot per 6000 acres (USDA Forest Service). Therefore, the complexity of those data led to an inconsistency of estimates from state-to-state (Chojnacky unpublished).

Finally, average ρ and η from a recent North Carolina field study data were also assessed (Hazel et al. unpublished). In this study, field measurements were made using prism sweep (Bebber and Thomas 2003) and line intercept methods (Van Wagner 1968) to measure post-harvest residual woody debris on 39 sites for which harvest records of all products including fuel chips were available.

Optimistic (high values of ρ and η in the reported range) and conservative values (low values for ρ and η in the reported range) were selected from obtained data and used as input data to estimate available logging residues for biomass production in North Carolina. These estimated residue volumes were converted to electricity energy equivalent (1.86 GWh per 1 dry kilo metric ton residues) derived from Gan and Smith (2006) and ethanol (70 gallons per 1 dry metric ton residues) based on USDA (2010). Assumptions were made that power plant efficiency was 35% and 1 dry ton biomass equals 2 green tons. Estimates of electricity from residues were compared with current consumption in North Carolina (U.S. Energy Information Administartion 2008) and expressed as percentages. Potential ethanol production was compared with North Carolina's RFS goal (Project Co-conveners and Steering Committee 2007).

The SRTS model was used to model how the availability of residues may change over a 30-year time span using different values for ρ and η, based on current harvesting patterns and management methods (Abt et al. 2000).

Results and Discussion

Average ρ were slightly higher (Figure 2) in the EU (23%) than in the southern US (19%). The ρ used by FIA were somewhat higher than those reported for the EU and elsewhere for the southeastern US (Figure 2). For FIA, ρ were based on derived data rather than empirical data. For FIA, there was an assumption that stump height is one foot and it was considered to be biomass and was included in the FIA residues estimates. A North Carolina field study based on 39 harvested sites in the Piedmont and Coastal Plain showed higher values than all other sources. All these results were from scattered single studies with localized data.

The value of ρ is a function of species composition and regional variation (Figure 2). As an example, ρ in the EU for spruce stands (29%) and broadleaf stands (25%) were higher than those from pine stands (16.5%). Explanations may include the fact that many hardwoods have a form that has much top and branch volume. As a comparison, ρ for pine stands in the EU (16.5%) were slightly higher than in the US (14%).

Data in Figure 3 from Virginia showed that ρ values were relatively higher in the Mountain region than in the Coastal and Piedmont regions (Parhizkar and Smith 2008). Explanations may include the fact that hardwood forests have been dominant in the Mountains of Virginia, but softwoods have been dominant in Coastal Plain (Parhizkar and Smith 2008). In addition,

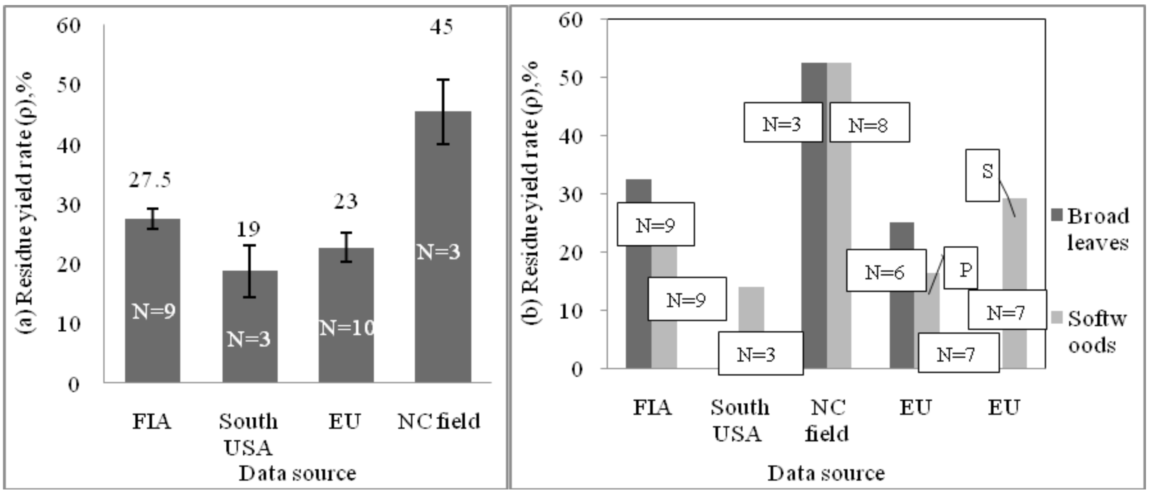

Figure 2. Distribution of average residue yield rates (ρ) derived from literature (the southern US including the US Forest Service Inventory and Analysis Program (FIA) and European Union (EU)) and North Carolina field data grouped by (a) all species and by (b) broadleaves and softwoods with confidence interval (α=0.05). Numbers of observations (N) are shown (a) inside and (b) above the bars. The average values are shown above each bar in chart (a). Acronyms: S – spruce, P – pine.

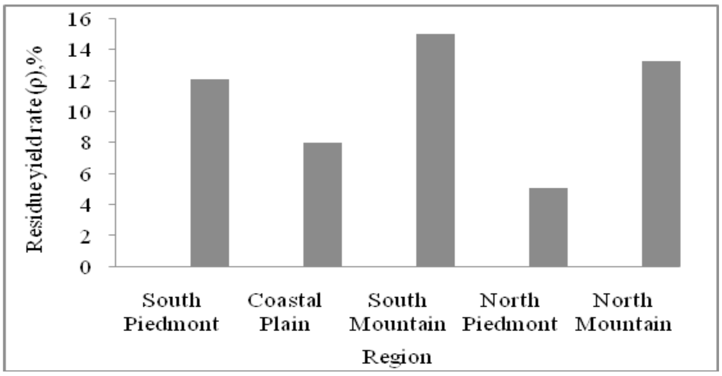

Figure 3. Distribution of residue yield rates (ρ) in regions of Virginia derived from literature.

due to limited accessibility, less mechanized harvesting technologies have been used in mountain region.

Based on the results, the conservative value for ρ was chosen as 20%, but the most optimistic was 50%. These rates were the most reasonable range that represented all values. Those values were then used for residue biomass estimates, because that included current situation with minimal biomass markets and the potential of residues in robust markets. An optimistic value 50% could be reasonable since the average of all species in NC field study was 45%, but for broadleaves and softwoods separately it was 52% (Figure 2). Average for the US was 18.7%, however, for the FIA data it was 27%.

For example, distribution of crown biomass and complete tree in final felling according to the National Technology Agency (2004) was 16% for Scots Pine and 27% for Norway Spruce. This was a study in Finland based on current harvesting practices (cut to length). According to FIA data for the US, residue rate for Hardwoods was 33%, but for Pine – 23%. We made the conclusion that even the same species composition had different rates. This was due to log-length technology used in the southern US and cut-to-length technology in Finland. The maturity of timber market changes the residue rate, because with developed markets and increased efficiency of timber industry more tree biomass can be utilized by traditional timber industry. In Finland smaller dimensions' trees were utilized, which reduced residue rate for Scots Pine compared with southern Pine.

Results (Figure 5) showed that there are similar recovery rates η in the southern US (62%) and in the EU (65%) with reported values from 46% to 80%. Results from meta-analysis were slightly higher than those 60% reported previously (Stokes, 1989).

The North Carolina field data of η (83%) were higher than reported elsewhere in literature; however, they reflect the increased recovery rates η in the Coastal Plain and Piedmont, where most of the data were collected (Figure 5).

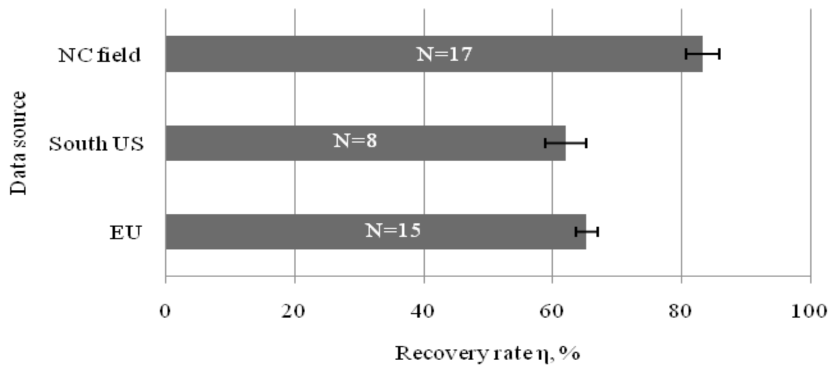

Figure 5. Distribution of recovery rates (η) derived from literature (the southern US and European Union (EU)) and North Carolina field data with confidence interval (α=0.05). Numbers of observations (N) are shown inside the bars.

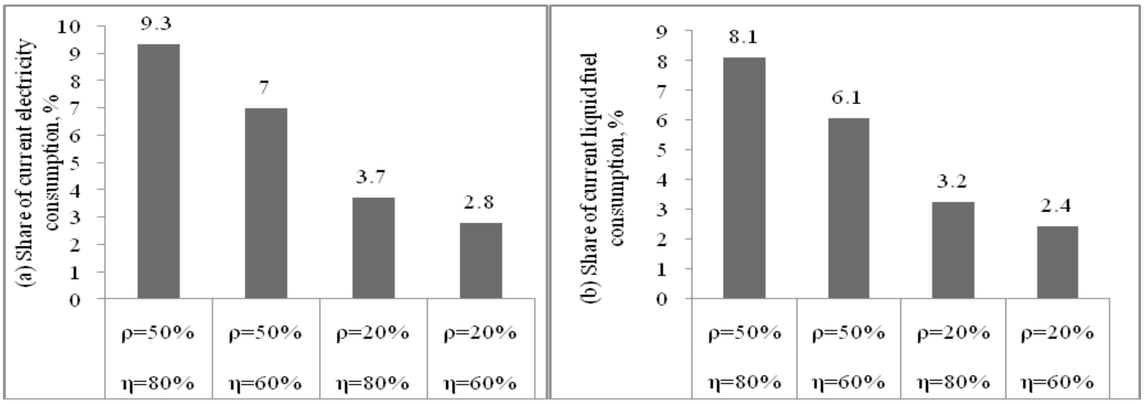

Figure 6. Residue biomass energy potential compared with current consumption of (a) electricity and (b) liquid fuels scenarios with different values of ρ and η applied.

According to Asikainen et al. (2008) η was 65% for mechanized cutting and – 50% for manual cutting. Residues consist of small pieces of tops, branches, limbs, needles and leaves (Perlack et al. 2005), making recovery difficult after manual cuttings. However, with the improved harvesting technology, the η increased to 65% and may be as high as 94%, when special integrated harvesting systems are applied and biomass markets are mature (Perlack et al. 2005). Despite the ability to attain high recovery rates, it is widely assumed that a substantial share of the residues should remain on site for environmental sustainability (Perlack et al. 2005). The η 80% and 60% were chosen for further analysis, because they represented current situation and future potential.

Based on our obtained data, the following values were applied to current FIA harvest data – 20% and 50% for ρ, and 60% and 80% for η. This resulted in four scenarios based on combinations of the two values for each variable: (1) ρ=50% and η=80% for scenario 1, (2) ρ=50% and η=60% for scenario 2 and etc. Logging residue estimates with scenario 1 were most optimistic, but scenario 4 was the most conservative.

To explore the potential impact of improved recovery estimates and efficiencies on policy development in North Carolina, residue estimates were converted to electricity and ethanol measures (Figure 6). For example, if the recoverable logging residues from logging operations were all used for electricity generation, it would displace coal-generated electricity and account for about 9.3% (scenario 1) and 2.8% (scenario 4) of current electricity consumption in North Carolina (Figure 6a).

These results indicated importance of ρ and η for availability estimates of residuals. Therefore, policymakers would need to consider different scenarios based on assumptions of harvesting system's efficiency. We assumed that all logging residues will be used either for electricity or liquid fuel production.

Residues from meta-analysis estimates were three times higher than those from Gan and Smith (2006). Results from Sub-Regional Timber Supply (SRTS) model runs were shown in Figure 7. Potential availability of residues in North Carolina was slightly decreasing for projections from year 2006 to 2036. Harvest in the SRTS projection were declining in the northern Coastal Plain and steady to increasing in the other regions. Overall there was a slight decline in harvest statewide over time. Since residuals were simply a constant factor applied to removals, the residual trend

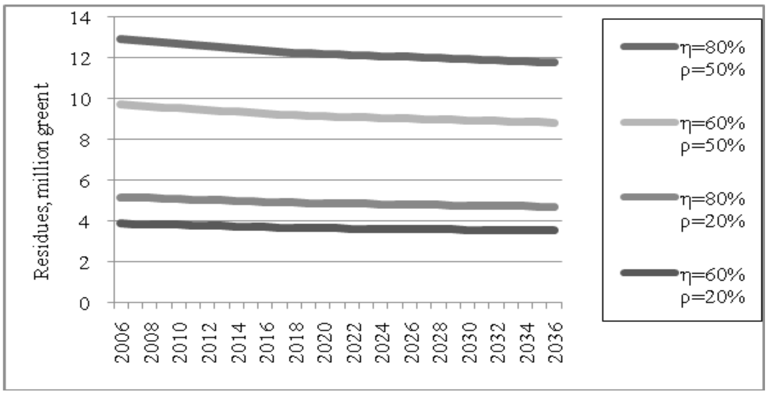

Figure 7. Available volumes of residue projected by SRTS model in North Carolina with optimistic and conservative ρ and η values. Time span was from 2006 to 2036.

followed the harvest trend. However, Gan and Smith (2006) projections showed increased levels of harvest and logging residue by 2030 in the southeastern US. They used 2002 Forest and Rangeland Renewable Resources Planning Act (RPA) assessment (Haynes 2003). They assumed a 70% recovery rate and an 18% increase in softwood harvest from 1997 to 2010 and an additional 26% from 2010 to 2020. For hardwoods they assumed a 23% increase in the first period and an additional 6.5% in the second period. They assumed a decline in residue yield rate ρ over time, but this was more than offset by the increased harvest. For SRTS constant demand was assumed which led to a 9% drop in harvest statewide from 2006 to 2036. There were increases in the Mountain and Piedmont regions, the southern coastal plain remained fairly constant, but there was a 35% drop in the northern coastal plain.

Estimates and projections with conservative values resulted in lower residue availability, which should be considered by policy makers. The potential volume of harvest residues in North Carolina was not sufficient to fully support policy-based goals for REPS and RFS, even with scenario 1 (optimistic). To meet these goals, additional biomass sources will be required. One way to increase residue availability is increased annual forest growth through fertilization (Linder et al. 2008). An additional source of bioenergy is stump harvesting. According to Melin et al. (2010) stump removal had minor impacts on forest ecological sustainability. In addition, more effective logistics would increase recovery rate η (Furness-Linden et al. 2008).

Conclusions

This paper assessed the residue yield rate ρ and recovery rate η for the southeastern US including that from FIA and North Carolina field study as well as for the EU. Average ρ were slightly higher in the EU (23%) than those in the southern US (19%). For FIA, ρ was higher and for North Carolina field study – even double the values found in the literature. The ρ were affected by species composition and harvesting technologies, where pine had the lowest values. It was problematic to state a single reasonable rate for North Carolina, because it depended on species, form of species and logging technology. Even FIA data showed variation between states and time.

We concluded that the wide range of values of these rates as reported in the literature is largely a function of the combination of tree forms, harvesting systems, and markets at time of harvest. Differences in forest stands change residue and recovery rates leading to inaccurate large-scale national estimates. Therefore, large-scale national residue estimates should be summed up from estimates from separate sub-regional forest stand estimates. We concluded that until rates are developed that are specific for species groups and typical harvesting systems, for residue availability estimates and policy-based goals, conservative values of these rates should be use (ρ=20% and η=60%).

Uncertainty regarding correct estimates of ρ and η can lead to imprecise estimates of potential renewable energy from logging residues. Ideally, studies should be conducted to empirically determine reasonable values of ρ and η.

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INFLUENCE OF THE PARTICLE PARAMETERS ON THE PROPERTIES OF BIOMASS BRIQUETTES

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Abstract
In the handling and usage processes, sufficient density and durability of biomass (straw, reed and hemp stalk) briquettes should be provided. For the briquettes density standards determined the value $\rho > 1.0$ g·cm^{-3}. In the densification process, usually fine grinded particles are used, which significantly increases energy consumption for stalk material cutting. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component (< 4 mesh) gives the best results. Calculated energy consumption for hemp stalk cutting to such size is > 12 kJ·kg^{-1}, but to the size of 100 mm – <1 kJ·kg^{-1}.
Calculated energy consumption for common reed cutting to sizes less than 3 mm was > 7 kJ·kg^{-1} but to the size of 20 mm – approximately 1 kJ·kg^{-1}. The goal of the investigation was to obtain the necessary density and durability of briquettes of larger biomass particles by arranging them. The orientation of the straw or reed or hemp stalks has to promote binding by the pressing operation. The article presents the investigation of straw, common reed and hemp biomass mechanical properties which influence the machine design and methods for biomass conditioning. The investigation of biomass briquetting energy and briquettes strength is also presented. Crushing force dependence on particle size for arranged structure briquettes was stated in laboratory experiments. The specific splitting force of arranged structure coarse chopped wheat straw and reed briquettes reached the value of 35 N·mm^{-1}. It is approximately the same as that of industrially produced wood briquettes. Splitting force of the hemp stalk briquettes reached 115 N·mm^{-1}. The density of the arranged reed and hemp stalk particles exceeds the recommended in the standards (1000 kg·m^{-3}) and reaches – 1185 kg·m^{-3} for the arranged hemp stalk particles with the length of 150mm and briquetting pressure – 212 MPa. The specific briquetting energy of coarsely chopped arranged reed and hemp stalk particles varied from 51.61 kJ·kg^{-1} to 67.23 kJ·kg^{-1}. For comparison, the finely chopped reed particle briquetting energy gave the maximum specific energy – 40 kJ·kg^{-1}. The splitting force of the hemp stalk briquettes reached 133.33 N·mm^{-1}.
Key words: briquette, hemp, straw, reed, solid biofuel, energy.

Introduction

The demand for different agricultural raw materials for biofuel production has increased in recent years, causing shortage of the traditional raw materials – sawdust and wood shavings. Biomass energy production can be realized only in accordance with ecosystem approach and good understanding of agricultural ecosystem function.

Growing of hemp, which is a good fibre, oil and biofuel resource, can be a good alternative source for energy producing. Hemp is a phytosanitary plant that enables its introduction into each crop rotation, practically after any plant. The yield of industrial hemp produces 10–15 tons of biomass per hectare plantation. It is estimated that cultivation of 1 ha hemp absorbs about 2.5 tons of CO_2, which contributes significantly to the lessening of the greenhouse effect (Mankowski J., Kolodziej J. 2008). Hemp with its rich leafage suppresses weeds, and leaves left on the soil after harvesting improve the soil structure (Poiša L. et al., 2010). In 2009, in Latvia about 200 ha were planted with hemp. To successfully develop the industry, the need to sow hemp is at least 1000 ha (Ulme A. et al., 2010). Latvia University of Agriculture provides growing experiments with two varieties: variety Bialobrezskie for fibre production and local hemp Purini, which has been grown in Latvia for 200 years, for seed (Poiša L. et al., 2010).

Particle size and shape are of great importance for briquetting. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component (< 4 mesh) gives the best results (Grover P.D., Michra S.K. 1996). Calculated energy consumption for common reed cutting to that size was > 5 kJ kg^{-1}, but o the size of 20 mm – approximately 1 kJ·kg^{-1} (Kronbergs E., 2006; Kakitis A., 2004), whereas energy consumption for hemp stalk cutting to the size of 6 – 8 mm is > 12 kJ·kg^{-1}, and to the size of 100 mm – <1 kJ·kg^{-1}.

The goal of the investigation was to obtain the necessary density and durability of briquettes of larger biomass particles by arranging them. The orientation of straw or reed or hemp stalks had to promote binding by the pressing operation.

Theoretical analysis of briquetting process was stated before the experiments. If particles are inserted in the briquetting die without arranging, they lay down perpendicularly to the pressing direction. Pressing force

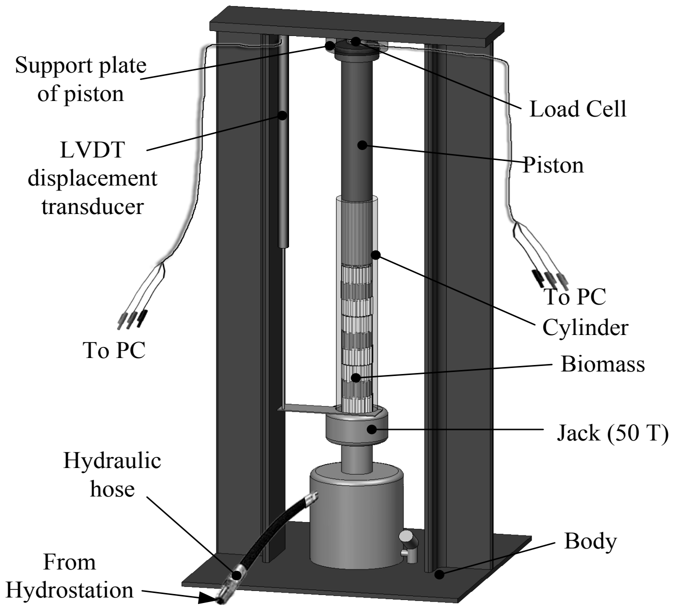


Figure 1. **Scheme of densification**

compacts the particles, but sharp adhesion between them does not occur because of the hard stalk particle surface. The reason is flattening of stalk material particles of the bonding surface area. To increase density and strength of briquettes it is necessary to maximize bonding surface area between the particles. Suitable arrangement of straw and reed particles in briquetting die allows changing deformation directions of particles. The stalk material curves and adhesion between particles increases.

As the pressing operation with oriented stalks was carried out on laboratory equipment, productivity of it was low. Therefore durability of briquettes has to be characterized by a different (not solid biofuel testing standard method) method where small amount of briquettes are sufficient. For laboratory experimental testing of briquettes crushing strength should be examined (Plištil D., et al., 2005).

Materials and methods

Compressive behaviour of stalk biomass is important for the design of biomass processing machines, shredders, briquetting press, etc. Hemp and reed stalks densification experiments were carried out by means of hydraulic press equipment in a closed die. To decrease briquetting energy, "cold" briquetting was carried out. It means that stalk material was pressured by piston in cylindrical closed die. Friction forces between biomass particles and inner cylinder wall did not increase energy consumption significantly because displacement of particles at large pressing force was small (Fig. 1).

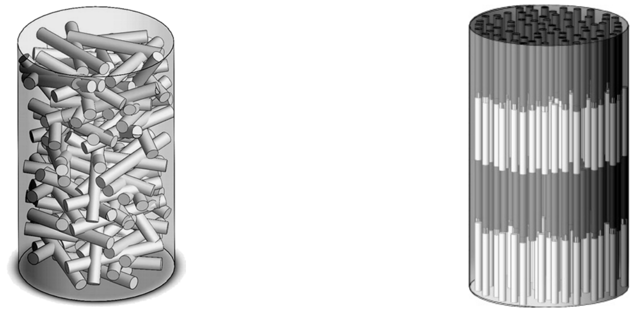
The length of reed and hemp stalks was 30, 60, 100, 150 and 300 mm. Experiments were carried out with unarranged reed and hemp stalks (length of particles was 30 mm), and with arranged reed and hemp stalks (length of particles was 60, 100, 150 and 300 mm).

Stalk material particles with certain length were arranged in a closed die as it is presented in Fig. 2b. The Arranged particles were located in the direction of longitudinal axe of the die. Overlapping of the ends of particles in different layers was 5 to 15 mm. Particles were slightly compacted in the arranging process to obtain the same mass of the material for every rerun. After arranging, the particles were compacted by hydraulic press with the maximum pressures in the closed die – 158 MPa and 212 MPa.

Length, diameter of briquette, and weight were measured. Density of briquettes was calculated on the basis of dimension measurement and weighing. For comparison, 30 mm length reed and hemp particles were placed in the briquetting die without arranging (Fig. 2a), and they were pressed with maximum pressure of 158 MPa and 212 MPa.

The pressing force and displacement of the piston were measured using load cell and LVDT displacement transducer. The load cell had force resolution of 1% of full scale, and the LVDT transducer had displacement resolution of 0.3 μm. For data acquisition, 24-bit virtual instrument ADC24 and software Picolog were used. As a result of the experiment, force_displacement curves were obtained (Fig. 3).

The total briquetting energy *E* was represented by the area underneath the entire load_displacement curve (Fig. 2). The calculation of the energy *E* was done according to equation (1):



a b

a – unarranged, b – arranged

Figure 2. **Arrangement of stalk material in a closed die before briquetting**

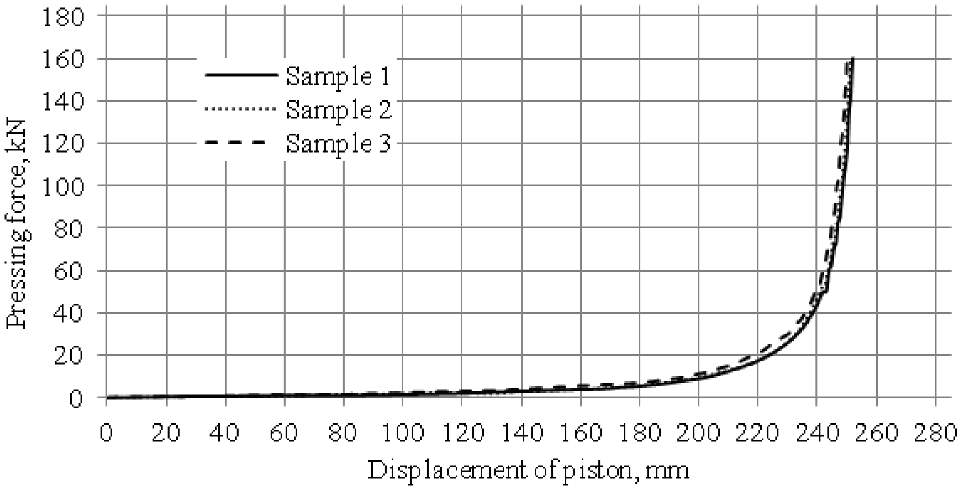


Figure 3. **Typical briquetting force_displacement curves of reed, particle length 150 mm.**

$$E = \left[\left(\frac{F_2 + F_1}{2} \right) \Delta z + \left(\frac{F_3 + F_2}{2} \right) \Delta z + ... + \left(\frac{F_n + F_{n-1}}{2} \right) \Delta z \right], \quad (1)$$

where E is energy, kJ; F_1 – first data point, kN; F_2 – second data point, kN; F_n – nth data point, kN; Dz – displacement interval between data points.

Specific briquetting energy was calculated for every briquette by equation:

$$E_s = \frac{E}{m}, \quad (2)$$

where E_s is specific briquetting energy, kJ·kg^{-1}; m – mass of briquette, kg.

The destruction force was investigated for 11 samples of each composition. The obtained force_ deformation diagrams were analyzed for all kinds of the tested biomass, and the average crushing force was calculated.

The diameter of the briquettes produced in the experimental pressing device was 36 mm. The length of the briquettes varied according to the closed die filling capacity before pressing. It depends on the biomass stalk diameter, flattening, and density. The average length of the briquette varied from 34 to 85 mm.

To compare the durability of different length briquettes, the specific splitting force was calculated:

$$F_s = \frac{F}{L}, \quad (3)$$

where F_s – specific splitting force, N·m^{-1}; F – splitting force, N; L – length of briquette, mm.

Compression tests were carried out on GUNT testing equipment. GUNT 20 materials testing machine with force resolution 1% and displacement resolution 10 µm and the maximal force for testing is 20 kN.

Results and discussion

In previous densification experiments of chopped straw, common reed stalk material particles and compositions with additives it was stated that compositions of straw particles from two fineness groups (2 – 3 mm and < 0.5 mm) compacted with pressure 230 MPa, have density > 1.0 g·cm^{-3}, if fineness proportion (amount of particles < 0.5) exceeds 25%. Density of 1.0 g·cm^{-3} has been obtained in densification of the straw and reed stalk material particle compositions with peat, if peat proportion exceeds 20%.

Fine communition of stalk material significantly increases energy of grinding. It has been stated that increasing of particle length from 1 to 100 mm decreases the specific cutting energy up to 40 times. Roughly shredded straw or reed material does not provide the necessary density and durability of briquettes, if material is unarranged in the closed die before cold briquetting.

To increase density and strength of briquettes it is necessary to maximize the bonding surface area between the particles. Suitable arrangement of the straw and reed particles in the briquetting die allows changing deformation directions of particles. The stalk material curves and adhesion between particles increases (D. Ancans, et al., 2011).

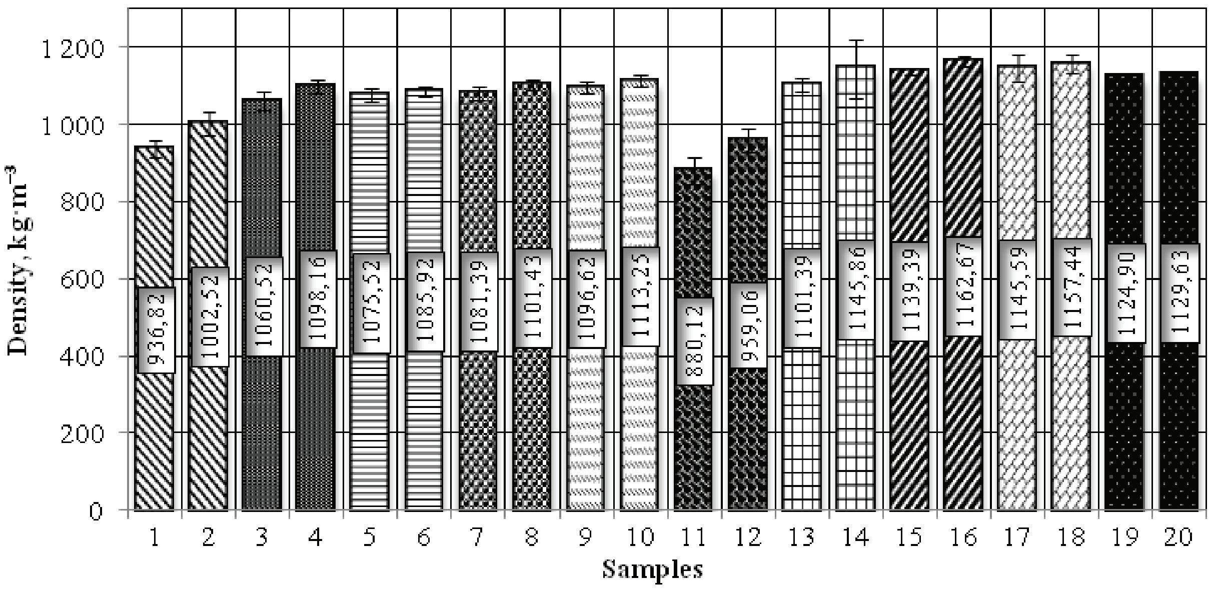
Results of the investigation of the briquettes density dependence on arranged particle size are presented in Fig. 4.

Density of arranged reed briquettes of the diameter of 36 mm varied between 1060 kg·m^{-3} (length of particles 60 mm) and 1113 kg·m^{-3} (300 mm).

Density of hemp stalk briquettes was 1162 kg·m^{-3} for particle length of 100 mm. Increase in the hemp particle length to 300 mm slightly decreased the density of briquettes. Results of the experiments showed that density of the briquettes recommended in the standards (1 g·cm^{-3}) was obtained for all lengths of arranged particles.

Decreasing of the briquetting pressure decreased the briquetting energy (Fig. 5). The maximum specific briquetting energy, 67.4 kJ·kg^{-1}, was obtained using the hemp stems with the particle length of 150 mm, briquette diameter of 36 mm, and the briquetting pressure of 212 MPa (specification in Fig. 5 – H150; 212 MPa). These briquettes showed the maximum density – 1157 kg m^{-3} (Fig. 4). The specific briquetting energy of the reed particles varied from 44.8 kJ·kg^{-1} to 59.3 kJ·kg^{-1}, but of hemp stalk particles – from 58.9 kJ·kg^{-1} to 67.4 kJ·kg^{-1}. Increasing of the length of reed particles from 30 to 300 mm increased the specific energy of briquetting 1.23 times. Increasing of the length of the hemp particles decreases the specific energy of briquetting.

Increasing of the pressing force increased the specific splitting force of all briquettes (Fig. 6). The specific splitting force of the hemp stalk briquettes was significantly by 20 to 50% greater than that of the reed particle briquettes.



1 Reed, 30 mm; 158 MPa
2 Reed, 30 mm; 212 MPa
3 Reed, 60 mm; 158 MPa
4 Reed, 60 mm; 212 MPa
5 Reed, 100 mm; 212 MPa
6 Reed, 100 mm; 212 MPa
7 Reed, 150 mm; 158 MPa
8 Reed, 150 mm; 212 MPa
9 Reed, 300 mm; 158 MPa
10 Reed, 300 mm; 212 MPa
11 Hemp stalks, 30 mm; 158MPa
12 Hemp stalks, 30 mm; 212 MPa
13 Hemp stalks, 60 mm; 158 MPa
14 Hemp stalks, 60 mm; 212 MPa
15 Hemp stalks, 100 mm; 158 MPa
16 Hemp stalks, 100 mm; 212 MPa
17 Hemp stalks, 150 mm; 158MPa
18 Hemp stalks, 150 mm; 212 MPa
19 Hemp stalks, 300 mm; 158MPa
20 Hemp stalks, 300 mm; 212 MPa

Figure 4. **Briquette density dependence on the length of particles**

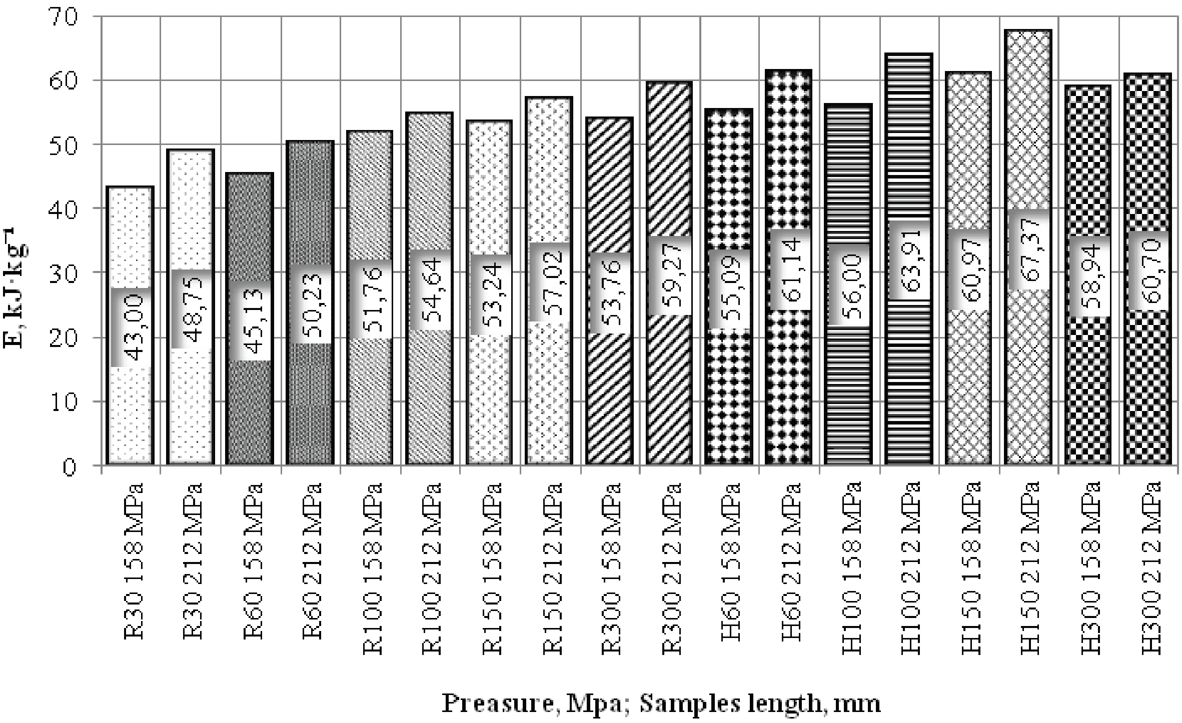


Figure 5. **Specific briquetting energy of briquettes**

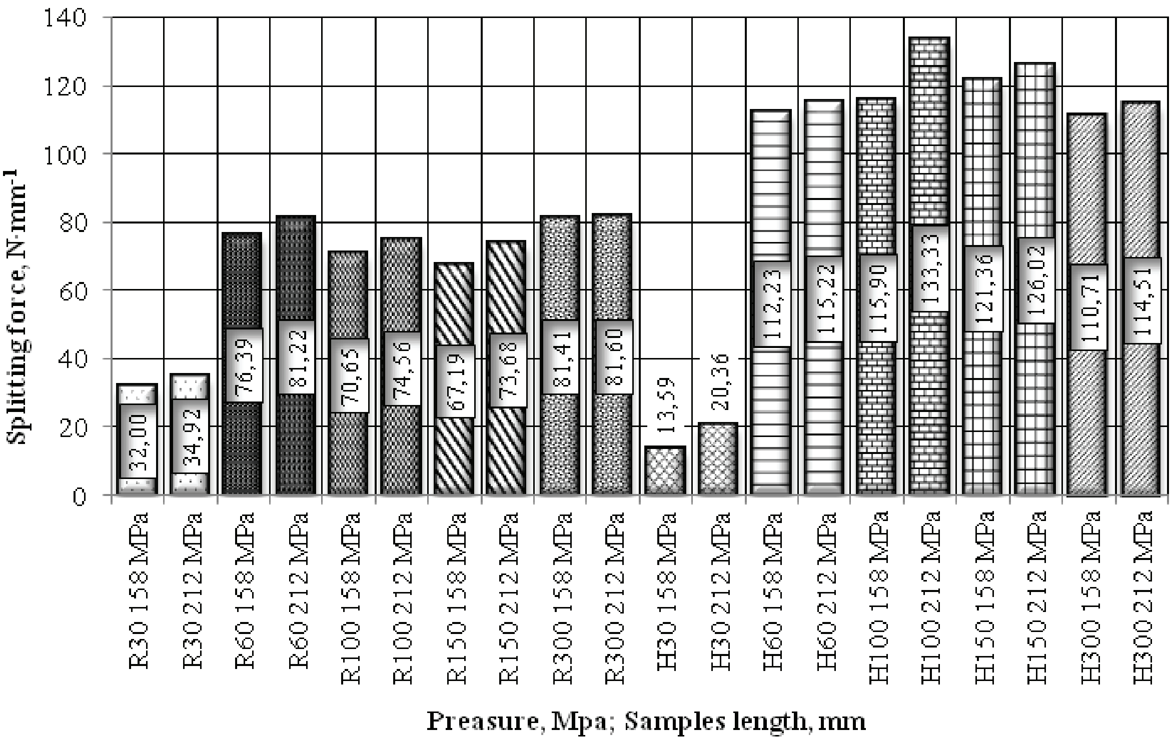


Figure 6. **Specific splitting force of briquettes**

For comparison industrially produced wood and unarranged reed briquettes were tested using the same method. Specific splitting force for industrially produced wood briquettes reached 38 $N \cdot mm^{-1}$, and this value can be taken as a base for comparison of experimentally made briquettes.

Dependence of the splitting force on the density of briquettes was evaluated from the

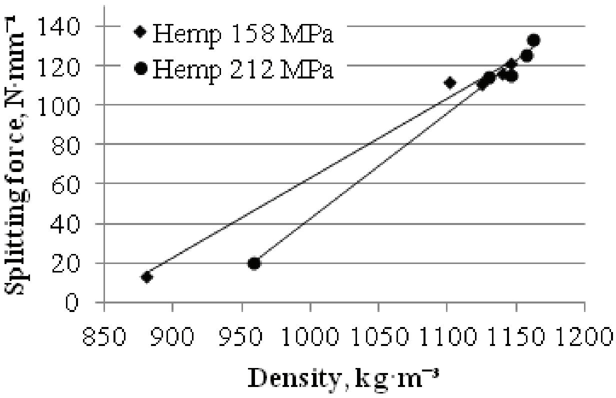


Figure 7. **Splitting force dependence on the hemp briquette density**

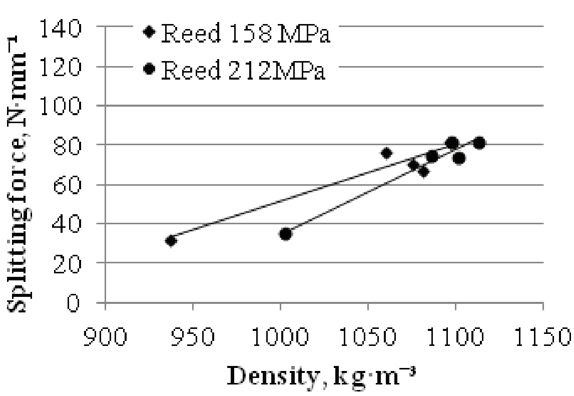


Figure 8. **Splitting force dependence on the reed briquette density**

results of experiments. Increasing of the density of briquettes increases durability of the briquettes for both tested biomass materials – reed and hemp (Figs. 7 and 8).

Conclusions

The density of the arranged reed and hemp stalk particles exceeded the recommended in the standards (1000 kg·m^{-3}) and reached the value of 1185 kg·m^{-3} for the arranged hemp stalk particles with the length of 150 mm and the briquetting pressure of 212 MPa.

The specific briquetting energy of coarsely chopped arranged reed and hemp stalk particles varied from 51.61 kJ·kg^{-1} to 67.23 kJ·kg^{-1}. For comparison, the finely chopped reed particle briquetting energy gave the maximum specific energy – 40 kJ·kg^{-1}.

The specific splitting force of the hemp stalk briquettes was 20 to 50% greater than the specific splitting force of the reed briquettes and reached the value of 133.33 N·mm^{-1}. It considerably exceeds the specific splitting force of the industrially produced wood briquettes – 38 N·mm^{-1}.

Arranged structure of biomass particles in briquetting die is recommended for significant increasing durability of stalk material briquettes.

New briquetting equipment is necessary to design for biomass particle arranging before pressing.

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EVALUATION OF BIOMASS COMPACTING MECHANISMS

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Abstract
Biomass compacting represents technology for the conversion of biomass into a solid biomass fuel in shape of briquettes and pellets. Previously chopped stalk biomass is the material of low bulk density (80 – 150 kg m^{-3}), therefore compacting of biomass is one of the important processes for effective handling, transport and storage of this biomass fuel material. This study was conducted to evaluate two biomass compacting mechanisms – hydraulic piston press, and screw press. Technical parameters of these two types of presses were analysed. The energy consumption for solid wood fuel mass unit production in briquetting process is used as the main criterion. The aim of evaluation is to find the most convenient compaction mechanism for energy crop mobile briquetting press design. Density of wood briquettes was determined experimentally and compared with recommendations of the standard LVS EN 14961-3:2011. Experimentally stated compacting density of natural biomass – common reed particles (*Phragmites Australis)* depends on the size of particles. Compositions of reed particles with peat allow obtaining briquettes density of > 1000 kg m^{-3}. Energy consumption for composition compacting is decreasing with increasing of peat proportion.
Key words: briquetting, density, screw press, piston press.

Introduction

After coal and oil, biomass is the third largest energy resource in the world. Until the mid-19th century, biomass dominated global energy consumption. Even though increased fossil – fuel use has prompted a reduction in biomass consumption for energy purposes over the past 50 years, biomass still provides about 1.25 billion tons of oil equivalent (Btoe) or about 14% of the world's annual energy consumption (Parikka M., 2004; Tumuluru J.S., 2010).

Wood fuels, agricultural straws, and energy crops are the most prominent biomass energy sources. In Latvia, approximately 14.6% of unfarmed agricultural land can be used for herbaceous energy crop growing. Herbaceous energy crops would be the main basis for solid biofuel production in agricultural ecosystem in future. Herbaceous energy crops – reed canary grass (*Phalaris arundinacea*) and hemp (*Cannabis sativa*) have been grown in recent years. Beside that there is possibility to utilize for bioenergy production natural biomass of common reeds (*Phragmites Australis*) overgrowing shorelines of Latvian more than 2000 lakes.

Biomass compacting represents technology for the conversion of biomass into a solid biomass fuel in shape of briquettes and pellets. Previously chopped stalk biomass is the material of low bulk density (80 – 150 kg m^{-3}), therefore compacting of biomass is one of the important processes for effective handling, transport and storage of this biomass fuel material.

Pelleting, briquetting, and extrusion processing are methods commonly used to achieve densification. The present paper deals with evaluation of two commonly used biomass densification mechanisms – hydraulic piston press, and screw press with the aim to find the most convenient compaction mechanism for energy crop mobile briquetting press design.

Materials and Methods

The technical data from manufacturers of 15 screw presses and 15 hydraulic piston presses were compared. The specific energy consumption of screw press and hydraulic piston press for biomass unit briquetting was calculated by formula:

$$E_{sc} = \frac{3600P}{Q} , \tag{1}$$

where

E_{sc} – specific energy of compacting mechanism, kJ kg^{-1};
P – power of compacting mechanism, kW;
Q – capacity of compacting mechanisms, kg h^{-1}.

For density determination, sawdust briquettes were obtained experimentally during compacting (Figure 1) with screw press and hydraulic piston press. Technical parameters of the hydraulic piston press: permissible moisture of input material 8 – 18%; density of produced briquettes 600 – 1100 kg m^{-3}; maximal hydraulic pressure 18 MPa; capacity 30 – 60 kg h^{-1}; power 4 kW. Technical parameters of the screw press: permissible moisture of input material 8 – 10%; density of produced briquettes 900 – 1400 kg m^{-3}; capacity 250 – 300 kg h^{-1}; power 22 kW; power of electric heater 6 kW. The sawdust briquettes made with screw press had a hexagon

Source: Woodworking…, 2011

Figure 1. **Equipment for briquetting experiments**

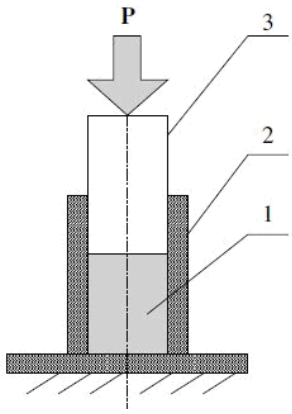

Figure 2. **The closed die for compacting: 1 – biomass, 2 – cylinder, 3 – piston**

cross-section with average edge dimension of 46 mm and with internal hole Ø20 mm. The sawdust briquettes made with hydraulic piston press had a round cross-section with average diameter of 64.5 mm and square form with edges dimension 64 x 150 mm. Briquettes densities were determined from the ratio of the mass to the volume of the briquette. For density calculation the weight of briquette was measured on electronic scales Sartorius GM312 with a division of 0.01 g, and size of briquettes was measured with sliding callipers (division 0.01 mm).

Laboratory compaction experiments were carried out in a closed die with diameter of 35 mm by means of hydraulic press equipment (Figure 2). A chopped common reed and reed-peat mixture material was used for experiments. For reed-peat mixture, peat was added in 15, 30 and 50% proportion. The modified wood shredder Tuenniseen GM-10 was used for reed chopping. The moisture content was determined according to the standard BS EN 14774-2:2009, where oven drying of the samples was carried out at 105 ± 2**ºC** (BS EN 14774-2, 2009). The dosage of 35 grams of chopped common reed particles and a mixture with peat additive was used for every briquette pressing.

During compacting of individual briquette, the force-displacement data were recorded by Pico Data Logger and computer. Energy requirement for compacting was obtained from force-displacement curves by graphical integration. The average values of measurements were calculated from 11 replicates.

Results and Discussion

The technical data from manufacturers of 15 screw presses and 15 hydraulic piston presses and specific energy consumption calculation for wood biomass unit briquetting are presented in Table 1 and Table 2. From the obtained results, for the screw press the calculated minimal average specific energy is 350 kJ kg^{-1}, maximal – 504 kJ kg^{-1} but for hydraulic piston press

Table 1

Screw press parameters

Screw press (Machine model)	Power, kW	Power of electric heater, kW	Capacity, kg h^{-1} (Min)	Capacity, kg h^{-1} (Max)	Specific energy, kJ kg^{-1} (Max)	Specific energy, kJ kg^{-1} (Min)	Average specific energy, kJ kg^{-1}
BIOMASSER SOLO BS06	4.2	4.5	40	60	783	522	653
SOLO 50	4.2	4.5	40	50	378	302	340
DUO 100	8.75	5	80	100	619	495	557
ZBJI	11	4.5	80	120	698	465	582
ZBJ-I	11	4.5	150	180	372	310	310
BIOMASSER DUO-SET	12.5	6.6	100	140	688	491	590
ZBJ-15	15	4.5	140	200	501	351	426
ПЭ-4	15	4.5	160	300	439	234	337
ZBJ-III	18.5	6.6	230	280	393	323	358
Zhongda	18.5	6.6	250	350	361	258	310
Hongji	18.5	6.6	250	350	361	258	310
ZBJ-ZY	22	9	320	500	349	223	286
Mingyang	22	6.6	240	320	429	322	376
HJJX-11	22	9	250	300	446	372	409
ПТБ	45	6.6	250	650	743	286	515

Source: Internet search results

Table 2

Hydraulic piston press parameters

Hydraulic piston press (Machine model)	Power, kW	Capacity, kg h^{-1} (Min)	Capacity, kg h^{-1} (Max)	Specific energy, kJ kg^{-1} (Max)	Specific energy, kJ kg^{-1} (Min)	Average specific energy, kJ kg^{-1}
BrikStar CS3-12	3	20	40	540	270	405
BrikStar CS4-12	4	30	60	480	240	360
OL.D 52	4	30	50	480	288	384
Weima C140	4	30	40	480	360	420
AECO 30	4.4	20	40	792	396	594
AECO 50	5.4	40	60	486	324	405
Weima C170	5.5	60	80	330	248	289
BP-100	5.6	43	63	469	320	395
Weima TH514	7.5	70	100	386	270	328
OL.D 62	7.5	50	70	540	386	463
BP 2000	18.5	150	225	444	296	370
MAX 350	24	350	500	247	173	210
BP 4000	30	600	750	180	144	162
RUF 600	37	500	600	266	222	244
RUF 1100	55	800	1000	248	198	223

Source: Internet search results

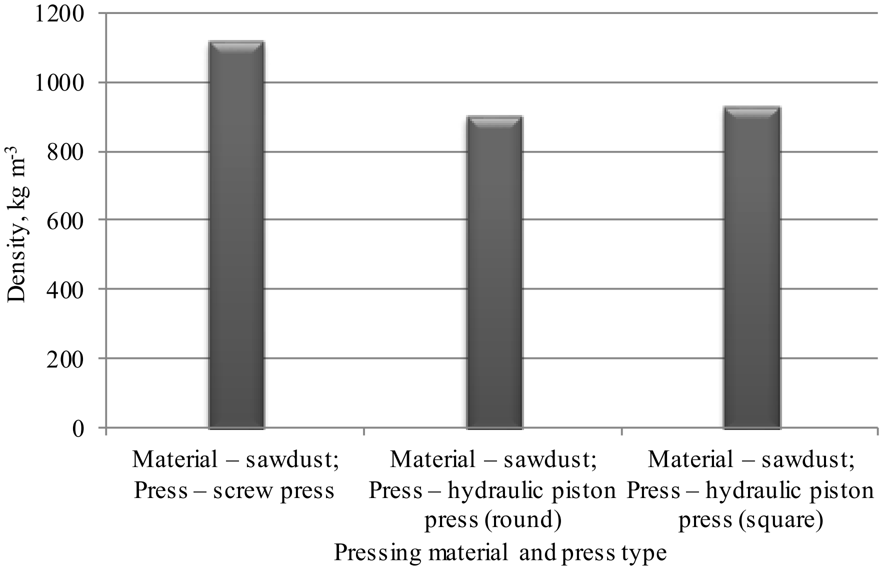

Figure 3**. Density of briquettes**

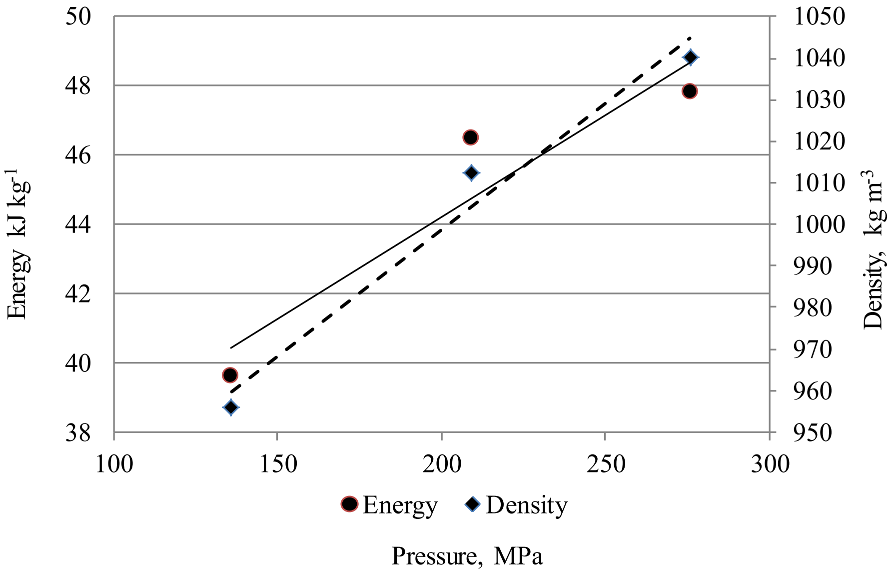

Figure 4**. Briquetting energy and briquettes density depending on pressing pressure**

the minimal average specific energy is 275 kJ kg^{-1}, maximal 424 kJ kg^{-1}. The specific energy differences depend on the minimal and maximal capacities of presses. Average specific compacting energy for the group of 15 screw presses is 407 kJ kg^{-1}, but for the group of 15 hydraulic piston presses – 350 kJ kg^{-1}.

The average specific energy consumption difference of 57 kJ kg^{-1} between the operation of screw press and hydraulic piston press can be explained with by additional energy consumption for biomass heating. Therefore, for mobile briquetting machines the hydraulic piston press mechanism is more preferable.

Density of sawdust briquettes obtained during compacting (Figure 3) with screw press and hydraulic piston press was determined 1122 kg m^{-3} for screw press briquettes, 902 kg m^{-3} for hydraulic piston press briquettes with a round cross-section and 930 kg m^{-3} with a square cross-section.

Density of experimentally produced wood briquettes was compared with recommendations of the standard LVS EN 14961-3:2011. This standard specification of wood briquettes for non-industrial use has two groups, A and B, with recommended densities DE1.0 $\geq$ 1.0 g cm^3 and DE0.9 $\geq$ 0.9 g cm^3 accordingly. There are no significant differences between standard LVS EN 14961-3:2011 density recommendations and determined density of wood briquettes produced with the screw press and the hydraulic piston press. The technical properties of the hydraulic piston press let to increase density of briquettes if friction forces in compaction die are enlarged.

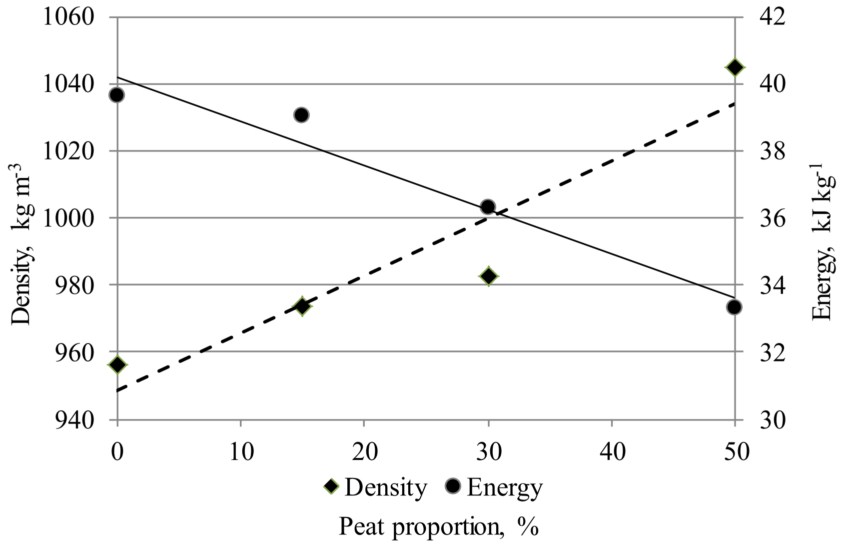

Figure 5. **Briquettes density and briquetting energy depending on peat proportion**

In previous experiments, the stated common reed stalk material ultimate tensile strength was 256 ± 27 N mm^{-2}. This value proved that common reeds are the strongest material among other energy crops, such as wheat and rape straw and reed canary grass, and could be regarded as representative energy crop of this group. Figure 4 shows that increasing compacting pressure from 136 to 276 MPa, the densities of reed briquettes are increasing from 956 to 1040 kg m^{-3}. For compacting experiments were used three pressure levels – 136, 206, and 276 MPa. Specific pressing energy was increasing from 39 to 47 kJ kg^{-1}, but 1000 kg m^{-3} density was achieved only for compacting pressure > 200 MPa. The resulting highest coefficient of determination for compacting data R^2 was determined for density 0.97 and for specific pressing energy 0.88.

Figure 5 shows the pressing energy consumption for briquetting common reeds with peat additive of up to 50%, and the density of produced briquettes. Maximum pressure of 136 MPa was achieved in compacting. Obtained results show that increasing peat additive up to 50%, specific compacting energy reduced from 39 to 33 kJ kg^{-1} and density increased from 956 to 1044 kg m^{-3}.

The resulting highest coefficient of determination R^2 was determined for density 0.95 and for specific energy 0.89. The present results show that peat additive is increasing the density of common reed particle briquettes and is reducing the specific compacting energy.

Conclusions

Average specific compacting energy for the investigated group of 15 screw presses was 407 kJ kg^{-1}, but for the group of 15 hydraulic piston presses – 350 kJ kg^{-1}. The average specific energy consumption difference of 57 kJ kg^{-1} between the operation of screw press and hydraulic piston press can be explained by additional energy consumption for biomass heating. Therefore, for mobile briquetting machines the hydraulic piston press mechanism is more preferable.

There were no significant differences between the standard LVS EN 14961-3:2011 density recommendations (DE1.0 ≥ 1.0 g cm^3 and DE0.9 ≥ 0.9 g cm^3) and the determined density of wood briquettes produced with the screw press and hydraulic piston press. The technical properties of hydraulic piston press allow increasing the density of briquettes if friction forces in compaction die are enlarged. By increasing the compacting pressure of common reed particles from 136 to 276 MPa, the densities of reed briquettes were increasing from 956 to 1040 kg m^{-3}. According to this pressure change, the specific pressing energy was increasing from 39 to 47 kJ kg^{-1}, but 1000 kg m^{-3} density was achieved only for compacting pressure > 200 MPa.

Increasing peat additive up to 50% to common reed particles specific compacting energy reduced from 39 to 33 kJ kg^{-1} and density of briquettes increased from 956 to 1044 kg m^{-3}. Peat additive is increasing the density of common reed particle briquettes and is reducing the specific compacting energy.

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WATER HEATING EFFECTIVENESS OF SEMI-SPHERICAL SOLAR COLLECTOR

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Abstract
Energy gain from a solar collector depends not only on materials and technologies used in its construction, commonly characterized with efficiency of the collector, but also on the geometry of the absorber of solar collector. These factors together determine the effectiveness of the collector. While new materials and technologies are widely studied in the world, there are not enough investigations on the absorber geometry yet. The geometry of the solar collector is most important in Latvia and other northern countries because of their geographical and climatic conditions: the path of the sun is long in summer, and nebulosity is frequently considerable. For developing of new constructions of solar collectors, methods of calculations of energy received by several surfaces are necessary. Such method has been proposed in this work. Using this method of calculation it has been found that effectiveness of solar collector with semi-spherical absorber is 1.37 times greater than that of flat plate solar collector, using the same materials and technologies. Such semi-spherical solar collector has been manufactured and measurements of water heating have been carried out.
Key words: efficiency, effectiveness, semi-spherical, solar collector, water heating.

Introduction

Align with decrease in reserves of fossil fuel, as well as impact of use of fossil fuel on climate, in the world more attention has been paid to renewable sources of energy, including solar energy.

Also in Latvia the solar energy has been used, mostly in solar collectors for hot water production (Ziemelis et al. 2004; Kancevica et al. 2006). However, in Latvia, because of its geographical and climatic conditions there are some peculiarities in comparison with traditional solar energy using countries (Pelece 2008; Pelece et al 2008). In Latvia in summer, the length of day exceeds twelve and maximally reaches seventeen hours, accordingly also the path of the sun is long, but altitude of the sun is rather small (maximally 56 degrees above horizon), therefore also intensity of solar radiation is low. There is also frequently considerable nebulosity.

In winter the altitude of sun is very small (10^{o}) and the length of day is 7 h, therefore use of solar energy in winter in Latvia is not possible.

Because of mentioned above features traditional flat plate collector without tracking the sun is not appropriate enough for use in Latvia, but new collector constructions are required, that would be able to collect the energy from all sides as well as to use the diffused radiation more efficiently.

Ability of the solar collector to use solar energy has been frequently characterised with efficiency, which has been defined as ratio between energy gain from solar collector and solar energy incident to the absorber. However, this efficiency depends only on materials and methods used in construction of the solar collector, but not on shape and orientation of the collector as well as other factors influencing energy incident to absorber.

In this article we propose to use term "effectiveness", taking into account also geometry of the absorber, instead of "efficiency". Such approach allows evaluating energy gain from solar collectors with absorber of other shape, not only flat, for example, semi-spherical absorber.

It has been found that effectiveness of a solar collector with semi-spherical absorber is 1.37 times greater than that of a flat plate solar collector, using the same materials and technologies. Such semi-spherical solar collector has been manufactured and measurements of water heating have been carried out. Good coincidence between the calculated and the measured results has been obtained.

Materials and methods

Measurements have been carried out at Ulbroka, where solar collector and measuring devices are situated on the roof of Institute of Agricultural Machines (5 storey building).

Measurements of the global solar radiation have been performed using an ISO 1. class pyranometer from "Kipp&Zonen". Measurements have been performed automatically, taking intensity of radiation after every 5 minutes and accumulating data in a logger. Thereafter from these data the daily energy density has been calculated. Measurements have been carried out from April 2008 till November 2010.

Data on the nebulosity from "Latvian Environment, Geology and Meteorology Centre" have been obtained. The nebulosity is evaluated visually in grades from 0 (clear sky) to 10 (entirely overcast) according to the World Meteorology Organization methodology after every 3 hours.

Measurements of the received energy of the solar collector have been performed using a new

Source: made by the authors

Figure 1. **Semi-spherical solar collector**

construction – solar collector with a semi-spherical absorber, shown in Fig. 1.

The absorber of the collector is made from copper sheet (thickness 1 mm) shaped as a dome and coloured black. The collector is covered with a transparent polyethylene terephthalate (PET) dome. Radius of the collector is 0.56 m, which corresponds to a 1 m^2 base area. Inside the absorber is a copper tube shaped close to the absorber, in which the heat remover (water) flows. Diameter of the tube is 10 mm, but length - 21 m. Water flow ensures the pump with productivity of approximately 30 l h^{-1}.

Measurements with semi-spherical solar collector have been carried out from 1 August till 31 October 2009, almost every day from 8:00 till 19:00.

In order to measure energy gain from the semi-spherical solar collector, water flow was measured as well as temperature of incoming and outgoing water. Measurements of temperatures have been done using thermocouples and "Pico" TC-8 termologer, ensuring measurements automatically after every 5 minutes. Then a power of the collector can be calculated from formula (1):

$$N = C \cdot K \cdot (t_2 - t_1), \tag{1}$$

where

- N – power of collector, W;
- C – specific heat of water, J kg^{-1} K^{-1};
- K – water pump productivity, l s^{-1};
- t_1 – cold water (input) temperature, ºC;
- t_2 – hot water (output) temperature, ºC.

In order to calculate the daily energy gain from solar collector, from the values of power must be selected the positive ones. Then daily energy gain can be calculated using formula (2):

$$E = \sum N \cdot \Delta t \cdot 10^{-6}, \tag{2}$$

where

- E – daily energy sum, MJ;
- Δt – interval between measures, s.

The summing in formula (2) must include all positive (output water temperature higher than input temperature) values of the day.

A new convenient method for calculating the received solar energy of several shape and orientation surfaces – a method of effective area – has been proposed in this article. The effective area of some surface at some moment is equal to the area of projection of this surface at the plane perpendicular to solar beems.

Then power of the direct solar radiation received by the surface at the moment is:

$$J = I_0 \cdot L_{ef} \tag{3}$$

where

- J – power received by surface, W;
- I_0 – intensity of beem radiation on surface perpendicular to solar rays, W m^{-2};
- L_{ef} – effective area of the receiving surface, m^2.

The effective area characterises the power of solar energy received by the collector. For calculation of the energy received at some period this equation must be integrated via time.

On the other hand, efficiency usually used for characterizing the solar collectors describes their ability to use the received energy:

$$e = \frac{Q}{E_k} \tag{4}$$

where

e – efficiency of collector;

Q – energy gain from collector, J;

E_k – energy received by collector, J.

Efficiency of the collector depends only on materials and technologies used in its construction, but not on its shape, orientation, or tracking to the sun. For example, efficiency of a stationary mounted flat plate collector and the same tracking the sun, both constructed using identical materials and technologies, will be equivalent.

For complete characterization of the solar collector, these values, efficiency and effective area, must be used together. Therefore we offer characterize the solar collector with effectiveness, which is product of the efficiency and ratio of effective area to the area of the solar collector.

$$\eta = e \cdot \frac{L_{ef}}{L} \tag{5}$$

where

η – effectiveness of the collector;

L_{ef} – effective area of the collector, m^2;

L – area of the collector, m^2.

Energy received by solar collector E_k in formula (4) is equal to the product of effective area of the collector and the solar beam energy on surface perpendicular to sun rays:

$$E_k = L_{ef} \cdot E_M \tag{6}$$

where

E_M – solar beam energy on surface perpendicular to solar rays, Jm^{-2}.

Therefore effectiveness of the collector can be calculated:

$$\eta = e \cdot \frac{L_{ef}}{L} = \frac{Q}{L_{ef} \cdot E_M} \cdot \frac{L_{ef}}{L} = \frac{Q}{L \cdot E_M} \tag{7}$$

Solar beam energy on the surface perpendicular to sun rays E_M is the energy received by a flat plate collector with ideal tracking to the sun, or maximal possible received energy. So, effectiveness of the solar collector is the ratio between energy gain from the collector and maximal possible solar energy received by solar collector.

It must be taken into account that all these values are changing with the height and azimuth of the sun.

Results and discussion

The effective area and the calculated energy gain from several solar collectors on a clear day of June 22 are shown in table 1. Flat plate solar collectors at several tilt angles, semi-spherical, spherical and cylindrical solar collectors there are considered.

It can be seen from the table that the largest effective area and therefore greatest energy gain (with equal efficiency, or materials and technologies used in construction) characterizes the spherical and cylindrical collectors, next is semi-spherical collector.

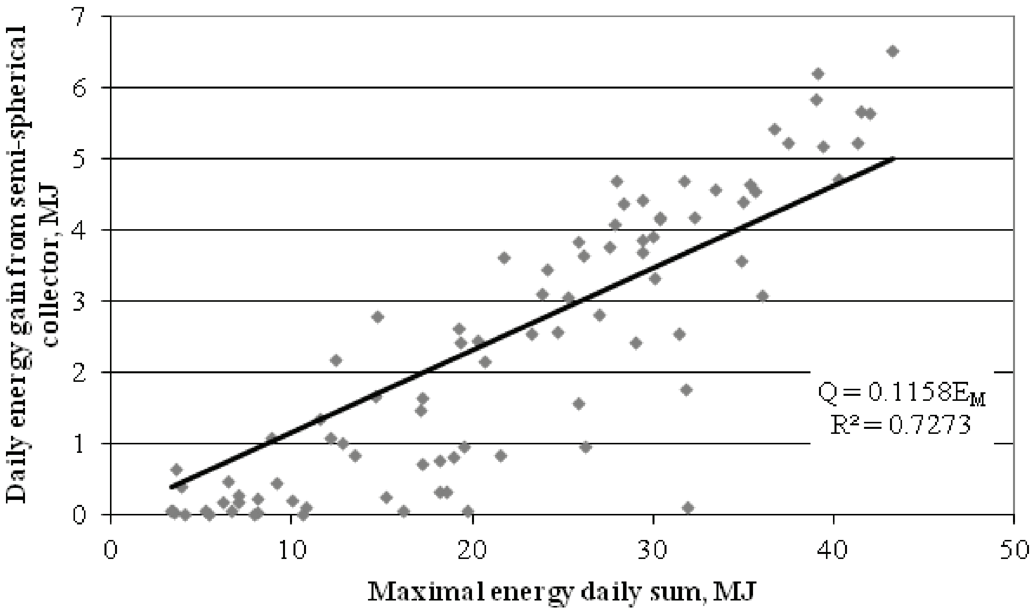
Energy gain from the stationary mounted flat plate collector is considerably smaller, and the smallest it is for the collector mounted at traditionally used 56° tilt angle. The effective area, of course, is not the only criteria for evaluation of the collector. Important is also the full surface area of the collector because of the heat loss from the whole area. For example, both spherical and cylindrical collectors have the effective area of 1 m^2 (if axis of the cylinder is perpendicular to solar rays) and therefore equal amount of received energy, but the cylindrical collector has smallest full surface area and therefore lowest heat loss. Taking into account both summary energy gain and mean effective area, expressed in percentage from all surface area, the best of all the considered forms of collectors is semi-spherical solar collector.

Table 1

Effective area and calculated received energy of several receiving surfaces

	Semi-spherical	Spherical	Cylindrical	Flat 34º	Flat 40º	Flat 56º
Radius, m	0.564	0.564	0.5			
Surface area, m^2	2.00	4.00	3.14	1	1	1
Mean effective area, m^2	0.74	1	1	0.48	0.47	0.41
Maximal effective area, m^2	0.9	1	1	1	0.99	0.92
Mean effective area, %	37	25	32	48	47	41
Energy, MJ	36	45	45	28.8	28	24.6

Source: made by the authors



Source: made by the authors

Figure 2. **Dependence of daily energy gain from the semi-spherical solar collector on the daily sum of maximal possible solar beam energy, 29 July to 31 October 2009 and 1 June to 30 September 2010**

Table 2

Calculated seasonal energy gain from several solar collectors

Modification of collector	E, MJ	E, kWh	E, % from tracking to the sun collector	Effectiveness
Tracking to the sun	1155	321	100	0.18
Semi-spherical	1058	294	92	0.17
Flat 40º tilted	805	224	70	0.13
Flat 56º tilted	771	214	67	0.12
Flat horizontal	685	190	59	0.11

Source: made by the authors

The effectiveness of the solar collector for all seasons can be evaluated using graphical method. Plotting the daily energy gain from solar collector via daily sum of maximal possible solar beam energy, the slope of this graph is effectiveness of the collector (Fig. 2).

Intercept of the graph equation must be zero, because if solar energy is zero, then also energy gain from solar collector is zero.

Thus it is obtained, that seasonal mean daily effectiveness of the semi-spherical solar collector is 0.12. It should be taken into account that semi-spherical solar collector used in these experiments was made from simple materials, without modern technologies such as selective coatings and others, therefore its efficiency is experimentally evaluated as 0.18. Increasing the efficiency by using up-to-date materials and technologies will proportionally increase also effectiveness.

The seasonal energy gain and effectiveness for several solar collectors is given in table 2. For better comparison, collectors of all kinds are taken with equal efficiency of 0.18 and with equal base area of 1 m^2.

Energy of solar radiation for these calculations has been evaluated using the method explained in our previous works (Pelece 2010). Real nebulosity data averaged over 5 years for each day have been used in these calculations.

The effectiveness of the semi-spherical collector in table 2 differs from that illustrated in Fig. 2 because the former shows the calculated long-time values but the latter – the real measurements taken in rather short time.

Table 2 shows that energy gain from semi-spherical solar collector makes 92% of the energy from tracking the sun flat plate collector. It is a very good ratio taking into account that tracking system is expensive and hard to exploit, while semi-spherical solar collector is simple, durable against wind and visually attractive.

On the other hand, semi-spherical solar collector produces 1.37 times more energy than the stationary (at traditional 56° tilt angle) flat plate solar collector.

The semi-spherical solar collector used in the present experiments is only a prototype. For practical use a larger collector would be better. Calculations show that semi-spherical solar collector with the radius of 1.25 m (and with the same efficiency as of that used in the experiments) produces 1300 kWh heat energy in a season, which exceeds the statistically mean hot water use of a household.

Conclusions

Energy gain from a solar collector can be characterized with effectiveness which includes both technological aspects described with efficiency and geometrical ones described with effective area.

A semi-spherical solar collector produces 1.37 times more energy than a stationary flat plate solar collector.

Energy gain from a semi-spherical solar collector with the radius of 1.25 m is sufficient for a statistically mean household in a summer season.

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THE TRACKING SYSTEM FOR SOLAR COLLECTORS WITH REFLECTORS

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Abstract
In the report advantages of the sun tracking collectors in comparison with stationary collectors are expounded. The realization principle of equatorial mounting of the sun tracking system and structural performance of the sun tracking collector with reflectors is viewed. The solar collector was provided with reflectors at the collector's rear side. The experimentally obtained energetic parameters of the sun tracking collector are compared to those of the ordinary flat-plate solar collector, and the assessment of energetic parameters is given. The placement of the sun tracking system elements on the collector with reflectors, functional scheme, working principle and characteristics of the sun tracking system are shown. The possibilities for improvement for the solar collectors with reflectors and their meaning are discussed.
Key words: solar energy, solar collector, tracking system.

Introduction

As positive factors for introduction of the sun tracking collector should be noted the following: the collector has an optimal condition of solar energy tracking, because such a construction secures that the solar collector's surface is tracking the sun all day long and the solar rays are striking it perpendicularly. As a result, the solar radiation losses which are related to the energy reflection from the collector surface will be decreased, and in this case the efficiency of a solar device will be at its maximum. For the covering of a sun tracking collector's absorber, a transparent material (glass) with a smoother surface can be used, which has higher solar radiation transmittance than material with a textured layer, which is normally used for industrially manufactured collectors. Flat-plate, smooth-faced surfaces are cleaned easily from dust, snow and rain spots. The sun tracking collectors released from dew frost and snow earlier in the morning, because it is directed to the sun at that moment. In this case collector produces as much heat energy as possible, and efficiency of a solar device increases. In addition, equipping the sun tracking collector with effective energy reflectors (mirrors) it is possible to obtain higher temperature. Also such type of collectors can be rotated and placed (stored) on a position which is not influenced by unfavourable weather conditions.

Tracking systems can be classified by the mode of their motion. This can take place about a single axis or about two axes. In the case of a single-axis mode, the motion can be in various ways: east-west, north-south, or parallel to the earth's axis. For full tracking or two-axis tracking, the position of the frame has to be changed in two planes – horizontal and vertical. The full tracking configuration collects the maximum possible sunshine, but the system for automatic management of such a process is rather complicated and expensive.

The task of the tracking system is to rotate and orientate the equipment of the solar energy collector so that the collector's surface is placed perpendicular to the solar rays all day long to receive maximum solar energy. Complexity of the sun tracking system, wherewith the price are largely determined by the accuracy of tracking and orientation, which is dependent on the collector type which is used. For example, solar radiation incidence angle deviation from normal of 20° for flat-plate collector does not create even noticeable captured radiation capacity reduction.

The higher accuracy for solar tracking system by solar collector with reflective mirrors is necessary (Latvia patent) (Putans et al., 2006), because the deviation of solar radiation on mirrors deals with the reflected solar radiation from the mirrors on the work surface of the collector's absorber. Besides this deviation is horizontal for cited collector and diagonally for collector without heel (Latvia patent) (Kancevica et al., 2007).

A more precise tracking system is necessary for solar collectors with energy concentrators like those of a parabolic trough collector or a parabolic dish reflector, besides, parabolic dish reflector the accurate as vertical as well as a horizontal plane orientation needed.

Materials and methods

Using meteorological data recording device MD-4 (Latvia patent) (Putans et al., 2011), at the Agency 'Research Institute of Agricultural Machinery' of Latvia University of Agriculture, during three years (2005-2007) from 1st March till 1st November in every 12 minutes, the meteorological parameters were measured. This device was envisaged for data acquisition (measuring and registration) about the air temperature, its relative humidity and intensity of solar radiation for the stationary and the sun tracking thermo battery. Summarizing the experimental data, the average yearly values for each of the three years

Table 1

Average values of meteorological parameters obtained by device MD-4 in Ulbroka 2005-2007

Month	T_{ov}, °C	E_{cst}, kWh m^{-2}	E_{ctr}, kWh m^{-2}
March	2.6	111	139
April	8.1	136	185
May	14.3	159	231
June	18.6	180	272
July	21.1	176	267
August	19.7	146	204
September	15.5	120	158
October	9.5	69	81
	S*E*	1096	1538

Source: Ziemelis et al., 2009

were obtained (Ziemelis et al., 2009) (Table 1): T_{ov} – average daily temperature, E_{cst} – amount of solar insolation energy daily received by a static, in south direction oriented surface, and E_{ctr} – amount of solar insolation energy daily received by tracking the sun to sun beams normally oriented surface. Data in Table 1 show that during the season, the sun tracking collector received 1.4 times more energy than the south oriented stationary collector, but during the summer months, for example, in June and July – 1.5 times more.

Using given methodology (Харченко, 1991) and the computer program MS Excel, the forecasted amount of the produced heat energy for stationary and sun tracking selective coating collectors were calculated (Ziemelis et al., 2009). The obtained data in the form of histograms are shown in Fig. 1: during the season 1 m^2 of the selective solar collector is surface area can produce 405 kWh of energy, but that of the sun tracking collector – 569 kWh, which is 1.4 times more. In some of summer months the difference was higher. It should be noted that if the water heated with solar collector is used intensively, the collector will work at $(T_{in} – T_o) < 50$ *°C* for long periods, so that the collector efficiency and amount of generation heat energy will be even higher.

Basically the sun following collector's devices consists of two blocks, supports with the rotation mechanism and mounted solar collector with or without solar energy reflectors on it and automatic sun tracking systems.

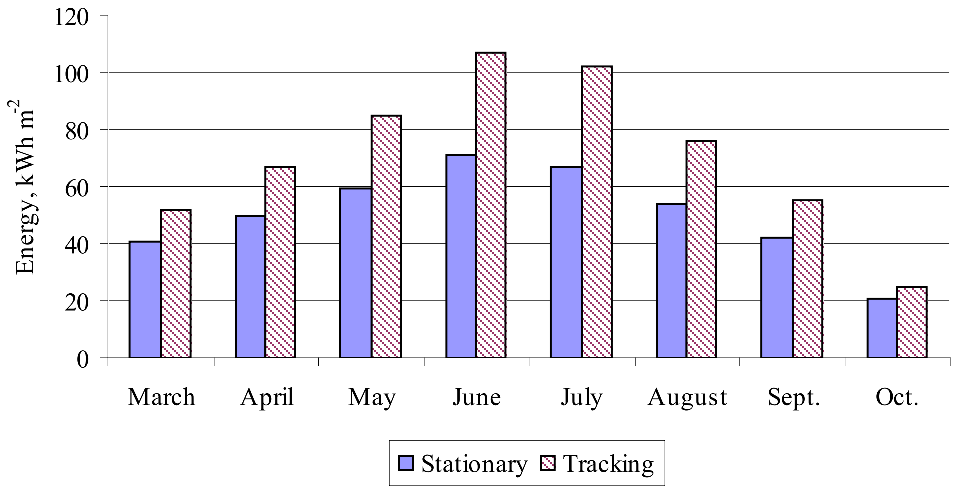
The sun tracking collector with reflectors

Due to the promotion work and for testing patented ideas, at the Agency 'Research Institute of Agricultural Machinery' of Latvia University of Agriculture tracking the sun solar energy collector with solar reflectors was constructed (Fig. 2). At solar collector with reflectors the rear surface of the absorber is receiving the solar radiation reflected from the two reflectors (mirrors). It is important that such a device works correctly. The collectors following the sun when secondary spindle of reducer turned. For example, for orientation to the sun on the true solar time, the reductor of device shall be fixed so that its secondary spindle symmetry axle with a vertical angle will be ($90° – \varphi$), would be directed to the North and focused on the polar star (φ – the degree of the latitude of the place). To take full advantage of the absorber's and mirror's surface areas, the collector must be equipped with a sensitive automatic tracking system. As it is known, the earth makes one rotation about its axis every 24 h, which means that 1 h of rotation equivalent to 15°. On 10 minutes solar ray will deviate for 2.5°.

The solar energy collector with automatic tracking system elements is shown on Fig. 2, where: 1 – solar energy collector; 2 – frame; 3 – reducer; 4 – screw mechanism for change the zenith angle of collector; 5 – support; 6 – chain belt; 7 – electric motor; 8 – reflectors (mirrors); 9 – slip contact of the potentiometer; 10 – slip ring of the potentiometer; 11 – resistor of the potentiometer; 12 – potentiometer axle; and 13 – electronics block of automatic tracking system. The collector comprises the frame (2), where between the side balks the flat-plate collector (1) is fixed (absorber is placed in the collector box and both sides of the box are covered by planes of glass). Two mirrors (8) are fastened to the frame (2). The collector and mirrors are secured symmetrically and perpendicular to the frame plane.

Research on parameters of the solar collector irradiated from both sides

Usually solar energy flat-plate collectors are constructed so that the sun heats the one to sun oriented solar energy collector's absorber side. In the box (other side of collector) the layer of heat insulation and heat absorber with a heat exchanger are placed. Due to the fact that from the heat insulation coated collector side there are less heat losses than from the side covered with glass, it is expected that by heating two glass-covered collector sides



Source: Ziemelis et al., 2009

Figure 1. **Calculated amount of heat energy produced by solar collectors at $\Delta T = T_{in} - T_o = 50$ °C** where: T_{in} – heat carrier inlet temperature into collector, °C; T_o – surrounding air temperature, °C.

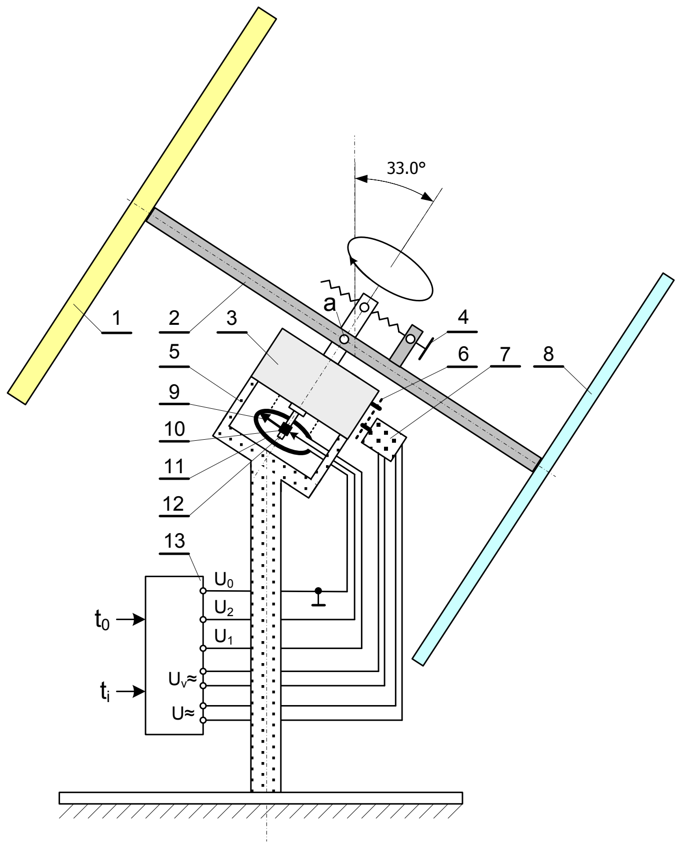


Figure 2. **Solar energy collector with elements of sun tracking system**

of the same intensity of radiation, it will be not produced twice as much energy in comparison with the standard flat-plate collector. Therefore to determine the energetic parameters of the collector irradiated from both sides, experimental investigations have been carried out.

In order to evaluate the produced amount of heat energy, in Table 2 as the reference point irradiation of the absorber only from one side with power 1000 W and 2000 W respectively is taken. From Table 2 it follows that when only one surface of the absorber with two times higher power is irradiated, 2.05 times higher amount of heat energy is produced. But when both surfaces of the absorber with power equal to the reference power are irradiated, 1.77 times more heat energy is produced.

Table 2

Energetic parameters at irradiation of the absorber surface with power of 1000 and 2000 W m^{-2}

No.	Parameters	Absorber irradiated by power		
		1000 W m^{-2}		2000 W m^{-2}
		75 min		
		One surface irradiated, another insulated	Both surfaces irradiated	One surface irradiated, another insulated
1	T_{in}-T_o *max*, °C	36.7	65.3	75.9
2	Power consumed, kJ	450	900	900
3	Power produced, kJ	185	328	379
4	Efficiency average	0.41	0.36	0.42
5	Gain	1	1.77	2.05

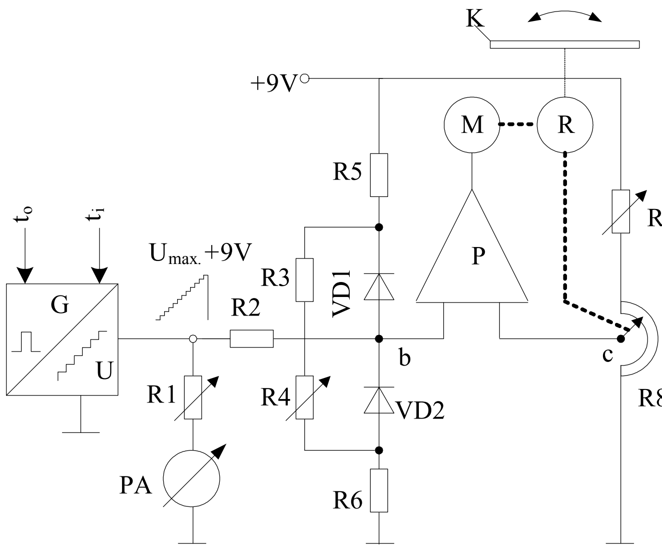


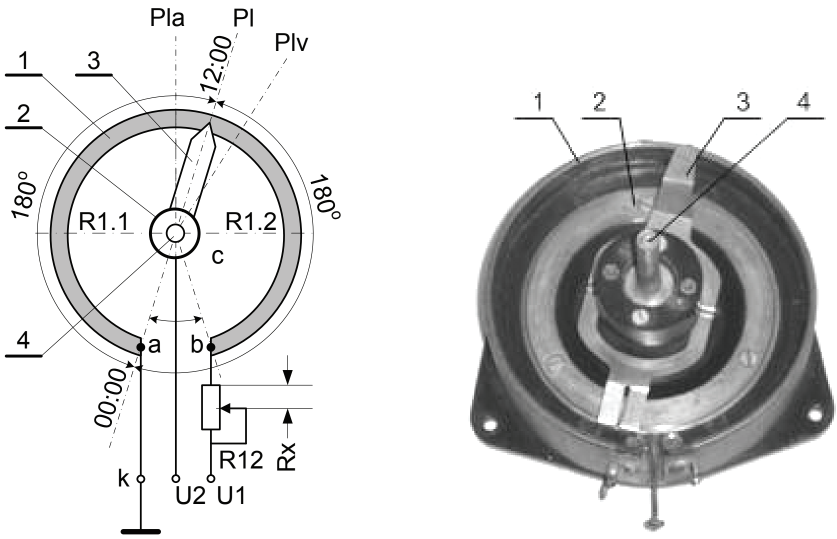
Figure 3. **Functional scheme of the automatic tracking system of solar energy collector with reflectors**

The functional scheme and working principle of the automatic sun tracking system for solar collector with reflectors

Different schemes of automatic control of the tracking system's work can be used. The scheme used in the present research for self-acting management of the device is presented in Fig. 3, where: *G* – voltage generator of real time; *PA* – real-time indicator; *R1*, *R2*, *R3*, *R4*, *R5*, *R6*, *VD1*, *VD2* – limiting devices for the turning angle of the collector; *P* – amplifier of the voltage and power; *M* – electric motor; *R* – reducer; *K* – solar energy collector; *R8* – potentiometer (alter-resistance) (see also Fig. 5), position sensor of solar energy collector (voltage divider); *R7* – turning speed range adjustment of the solar energy collector (variable resistors). The electronics block of solar automatic tracking system is shown in Fig. 4.

The automatic tracking system of solar collector with reflectors works as following. When real time voltage generator works, gradually increases the voltage on the generator output circuit. Each growth of the voltage impulse increases the current on indicator *PA*, that causes lead of indicator clockwise by showing the time, because the scale of the instrument graduated h. Similarly voltage on generator output circuit point *b* increases, which is connected to one of amplifier *P* inputs circuits. This increase of voltage upsets the balance of potentials on amplifier inputs (balance of voltage between points *b* and *c*) and leads tracking system reaction – on amplifier *P* output circuit appears voltage, start to turn the electric motor and reducer with on its axis fixed collector and potentiometer (voltage divider) *R8* slip contact. During rotation on the potentiometer slip contact (point *c*) increases the voltage, so the rotation will continue until the voltage difference on amplifier inputs

Figure 4. **The electronic block of automatic tracking system**



a b

Figure 5. **Potentiometer (alter-resistance) R8**:
a – schematic illustration; *b* – overview; 1 – potentiometer resistor (electrical resistance); 2 - slip ring of the potentiometer; 3 – slip contact of the potentiometer, 4 – axis; *U1* – the supply voltage to the potentiometer; *U2* – circuit output voltage of the potentiometer

disappear (between point's *b* and *c*). Then disappears the voltage on amplifier output circuit and the electric motor stops working. When next voltage impulse arrives, the process repeats. For the real time voltage generator with t_0 set up day start (zero-voltage on output circuit of the generator), but to t_i – for running time of an appropriate voltage.

Since the potentiometer electrical circuit is interconnected, that is the currents in all its elements are equal then:

$$\frac{U_2}{R_{1.1}} = \frac{U_1 - U_2}{R_{1.2} + R_X}, \quad (1)$$

where:

$$U_2 = U_1 \frac{R_{1.1}}{R_{1.1} + (R_{1.2} + R_X)}. \quad (2)$$

For the resistance slip contact of the potentiometer (3) located on the solar noon (*Pl)* time axis ($U2 = 0.5 \cdot U1$), the sum of resistance ($R1.2 + Rx$) must be equal to *R1.1*. If resistances $Rx = 0$, then solar noon time axis *Pl* ($U2 = 0.5 \cdot U1$) will move to the *Plv* and collector will take the noon time position earlier than if ($R1.2 + Rx) = R1.1$. But when increasing the resistance *Rx*, if ($R1.2 + Rx) > R1.1$, then on noon time (*Pla*) the collector will turn later. So, if the value of resistance *Rx* is changed, on the constant voltage increase of the automatic tracking system the electronics unit output circuit time of the day, it is possible to accelerate and slow down the turning speed of the solar energy collector and to match it to real movement of the sun, i.e., to adjust the turning speed of the collector at the time of equation (alignment).

Results and discussion

Summarizing the experimental data, the average yearly values (Table 1) and calculations of it show that during the season, the sun tracking collector receives 1.4 times more energy than the south oriented stationary collector, but during the summer months, for example, in June and July – 1.5 times more.

Due to the fact that heat insulation coated collector side has less heat losses than from the side covered with glass, it is expected that by heating two glass-covered collector sides of the same intensity of radiation it will not be produced twice as much energy in comparison with the standard flat-plate collector. Technical performance for solar collector with reflectors (solar collector irradiated from both sides) can be improved by using selective coating for the absorber and selective glassing, which generally decreases the losses of radiation energy.

The tracking solar energy collector with reflectors with 1 m^2 surface area can get 3 times more energy than the stationary, provided that the total surface area of the mirrors is 2 times greater than the absorber's surface area. It is possible to increase the amount of energy received by the tracking the sun collector by increasing the number of mirrors (Latvia patent) (Putans et al., 2008; Kancevica et al., 2007). For solar energy collector oriented all year exactly to the sun, it should be turned around the polar axis on the true solar time.

Fig. 1 demonstrates that during the season 1 m^2 surface area of the selective solar collector can produce 405 kWh of energy, but of the sun tracking collector – 569 kWh, which is 1.4 times more. In some of summer months the difference was higher. From Table 2 it follows that when only one surface of the absorber with two times higher power is irradiated, 2.05 times higher amount of heat energy is produced. But when both surfaces of the absorber with power equal to the reference power are irradiates, 1.77 times more heat energy is produced.

Conclusions

The tracking the sun collector without reflectors had an optimal condition of solar energy tracking, because such a construction secures that the solar collector's surface is tracking the sun all day long and the solar rays are striking it perpendicularly. As a result, it produced 1.4 times more heat energy in comparison with stationary operating flat-plate collector of the same size.

The sun tracking collectors released from dew frost and snow earlier in the morning, because it is directed to the sun at that moment. In this case the collector produced as much heat energy as possible, and efficiency of the solar device increased. Also this type of collectors can be rotated and placed (stored) on position, which is not influenced by unfavourable weather.

In addition, equipping the sun tracking collector with effective energy reflectors (mirrors) it is possible to obtain higher temperature. When the absorber of a collector is irradiated from both sides with equal radiation intensity, it produces 1.77 times more heat energy than in case it is irradiated only from one side, the other one having a heat barrier.

The design of the sun tracking solar collector with reflectors is simpler, if the absorber is irradiated from both sides, therefore this variant can be recommended for practical use.

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CRITERIA OF EFFECTIVENESS EVALUATION OF VARIABLE SPEED CENTRIFUGAL PUMPS IN HEATING AND COOLING SYSTEMS

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Abstract
The goal of this study is the derivation of evaluation criteria for effectiveness of variable speed circulators used in heating and cooling systems.
Proportional pressure control mode has been analyzed as a criterion for centrifugal pumps. For this reason, a great number of energy analyses have been realized for different pumps and a regression equation with a corresponding coefficient of determination has been derived.
As the result, the trend of reduction of energy consumption has been determined if the proportional pressure control mode is used in comparison with constant differential pressure control mode. The control modes are compared if the value of the duty point remains invariable for both modes. It has been found that the reduction of annual energy consumption can be achieved up to 33% if the proportional pressure control mode is applied with the deviation of 60% from the head value of duty point at zero flow.
There is also the change of efficiency level of circulators has been investigated in the article. It has been done at different deviations from nominal pump head. The regression equation with coefficient of determination has been derived.
Finally, it has been derived that the efficiency level drops up to 3% if variable speed centrifugal pumps are applied, and the deviation of the head value of best efficiency point (BEP) is up to 30% from its nominal value. A slight decrease of efficiency level is observed if the deviation from the nominal head value is up to 30%. If the head deviation is above 30% from its nominal value, then the efficiency level drops rapidly.
Key words: centrifugal pump, control mode, efficiency.

Introduction

Today with the rapid increase of energy production costs in the world, higher attention is paid to improvement of energy efficiency level. About 20% of the total electrical energy produced in the world has been consumed by pumps and pumping systems and almost half of that can be saved up (Giribone P. et al., 2006).

There are a lot of technical aspects which should be taken into consideration in order to optimize operation of pumping systems with a focus on pump control modes. Each separate pumping system is described with its own specific features and is thus characterized with an individual approach.

Selecting the pumping technology is also very crucial if the duty point is located at the most optimal zone of pump curve, thus achieving the highest possible level of energy efficiency.

With the certain research focused on the evaluation of operation of pumping systems, it's possible to substantially increase the total level of efficiency in engineering networks, thus contributing to energy saving in the world.

Materials and Methods

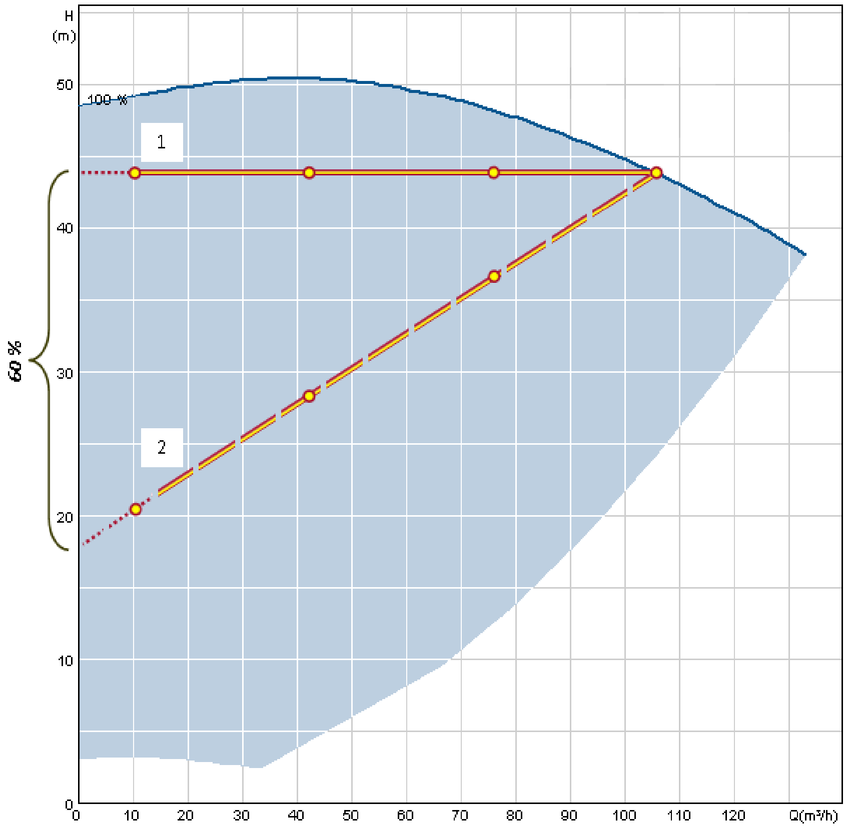
Evaluation of savings' potential if the proportional pressure control mode is applied for circulators in comparison with constant differential pressure control mode

Circulators are normally controlled via the constant differential pressure or proportional pressure control mode in heating and cooling systems (Machine Design by Engineers for Engineers, 2002). The proportional pressure control mode is the most efficient mode of the control for circulators. Thus it's very crucial to estimate the potential reduction of energy consumption if proportional pressure control is used in comparison with constant differential pressure control.

The proportional pressure control mode is generally recommended for the systems where the pressure drops, splits between piping system and control valves, is mostly dedicated to the piping system (Skovgaard, A., 2004). Thus the proportional pressure control is advisable to use in heating and cooling systems with relatively long piping network.

Besides that, the proportional pressure control mode should be used if two-way control valves are installed in the system (Skovgaard, A., 2004). The pump will reduce the speed if the valve is closing. The adjusted head value is being adapted in accordance with flow variations during the heating process if the proportional pressure control mode is used.

The load profile of heating system is taken into account in order to analyze the consumption of electrical energy of pumping system if the proportional pressure control mode with different deviations from the head value of duty point at zero flow is used.



Source: Grundfos Management A/S, 2011

Figure 1. **Control modes for circulators (1 – constant differential pressure control mode; 2 – calculated proportional pressure control mode with linear influence)**

It has been assumed that the annual operation of pumping system is 6840 hours and the load profile (German Blue Angel Labelling Scheme, 2002) is divided into four parts with different flow values: 100%, 75%, 50% and 25% of flow rate in the duty point. In its turn, each flow component corresponds to certain duration of operational time as a part of the total duration of operation per year (German Blue Angel Labelling Scheme, 2002; Europump, 2001).

Each flow component corresponds to certain duration of operational time in the following way (Trinath S., Amitabh G., 2009):

100% -> 6%,
75% -> 15%,
50% -> 35%,
25% -> 44%.

The energy consumption, having realized a variety of proportional pressure variants, has been compared with the energy consumption if the constant pressure control mode is applied.

During the analysis of the calculated proportional pressure control mode with different deviations from the head value of duty point at zero flow rate (20%, 40% and 60%), there has been carried out the calculation of annual energy consumption for centrifugal pumps of various designs (Pump School, 1998; KSB Aktiengesellschaft, 2010) (Figure 1).

There are various limitations which have been taken into consideration during the energy calculation. The limitations are as follows:

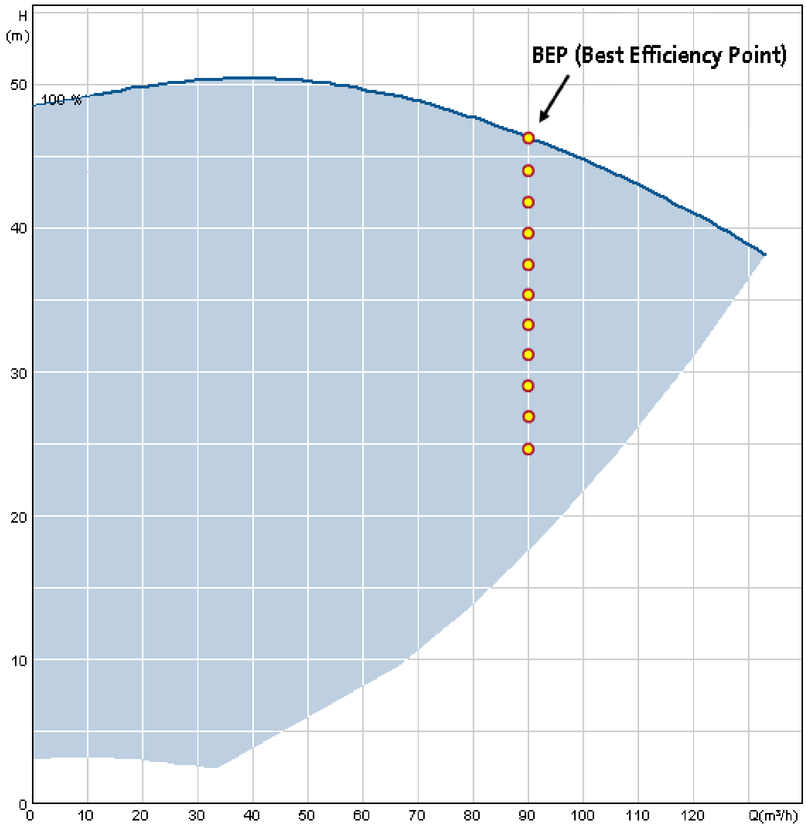
– the calculated proportional pressure control mode with linear influence has been chosen,
– each duty point is met with its appropriate pump,
– the deviation from pump efficiency optimum is up to 3% for each duty point,
– the deviation from the head value of duty point at zero flow rate varies from 0 up to 60%.

During the study, 8 centrifugal pumps of various designs have been analyzed (Grundfos Management A/S, 2011; Wilo SE, 2010).

Evaluation of the change of the efficiency level of centrifugal pumps according to the location of the duty point

Selecting the pumping equipment, it's very important that a duty point is located at the most optimal zone of pump curve. In this case it is possible to achieve the highest possible level of energy efficiency. Of course, the efficiency level drops if centrifugal pumps operate with a lower rotational frequency.

So, it is very crucial to determine the room for improvement of the efficiency level of centrifugal pumps in heating and cooling systems if there are different deviations of duty point location from the head value of the best efficiency point (BEP).



Source: Grundfos Management A/S, 2011

Figure 2. **Deviation of duty point from the head value of the BEP**

The following equation (1) can be used for the determination of pump efficiency level (Giribone P. et al., 2006).

$$\eta = \frac{\rho \bullet g \bullet Q \bullet H}{P_2}. \quad (1)$$

In this equation (1), η represents the pump efficiency level in %, ρ represents the liquid density in kg m^{-3}, g represents the acceleration of gravity (9.81 m s^{-2}), Q represents the flow rate in m^3 s^{-1}, H represents the head in m and P_2 denotes the shaft power in kW.

Centrifugal pumps of various designs were investigated during the analysis of pumps' efficiency change if there are different deviations of duty point from the head value of the BEP (Figure 2).

There are certain limitations which have been taken into consideration during the investigation. These limitations are as follows:

– the maximum deviation of duty point from the head value of BEP is 75%,
– each analysis of head deviation from its nominal value is met with its appropriate pump.

During the study, 16 centrifugal pumps of various designs have been considered (Grundfos Management A/S, 2011; Wilo SE, 2010).

Results and Discussion

Evaluation of savings' potential if the proportional pressure control mode is applied for circulators in comparison with the constant differential pressure control mode

As a result of the research, the regression equation of the polynomial trend type ($y=\alpha_0+\alpha_1*x+\alpha_2*x^2+\varepsilon$) and the respective coefficient of determination (R^2) has been derived.

$$y = -0.1332 \bullet x^2 + 0.6352 \bullet x - 5 \bullet 10^{-6}$$
$$R^2 = 0.9845 \quad (2)$$

In this equation (2), y represents the reduction of energy consumption in % if the calculated proportional pressure control with different deviations from the head value of the duty point at zero flow rate is applied (in comparison with the constant differential pressure control mode) and x denotes the deviation from the head value of the specific duty point at zero flow rate in %.

The equation (2) can be used as a tool for evaluation of the potential reduction of energy consumption at different deviations from the head value of duty point at zero flow. The potential reduction of energy consumption is estimated in comparison with the usage of conventional pump control mode (constant

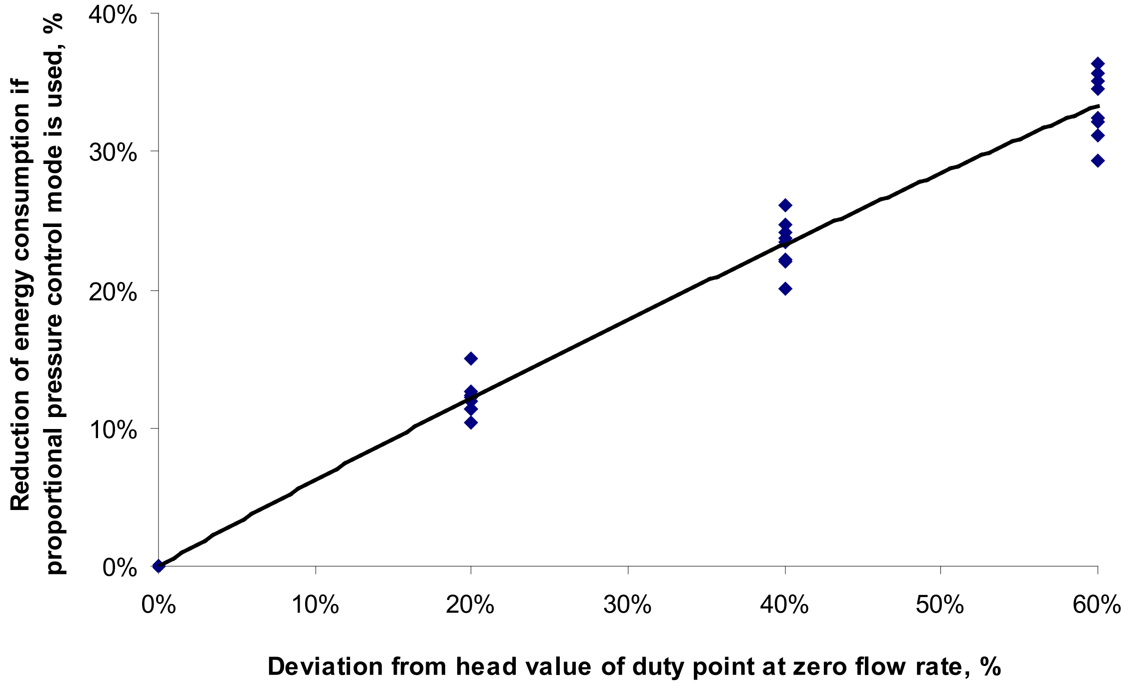


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Figure 3. **Reduction of energy consumption if the calculated proportional pressure control mode with different deviations from the head value of duty point at zero flow rate is applied (in comparison with the constant differential pressure control mode)**

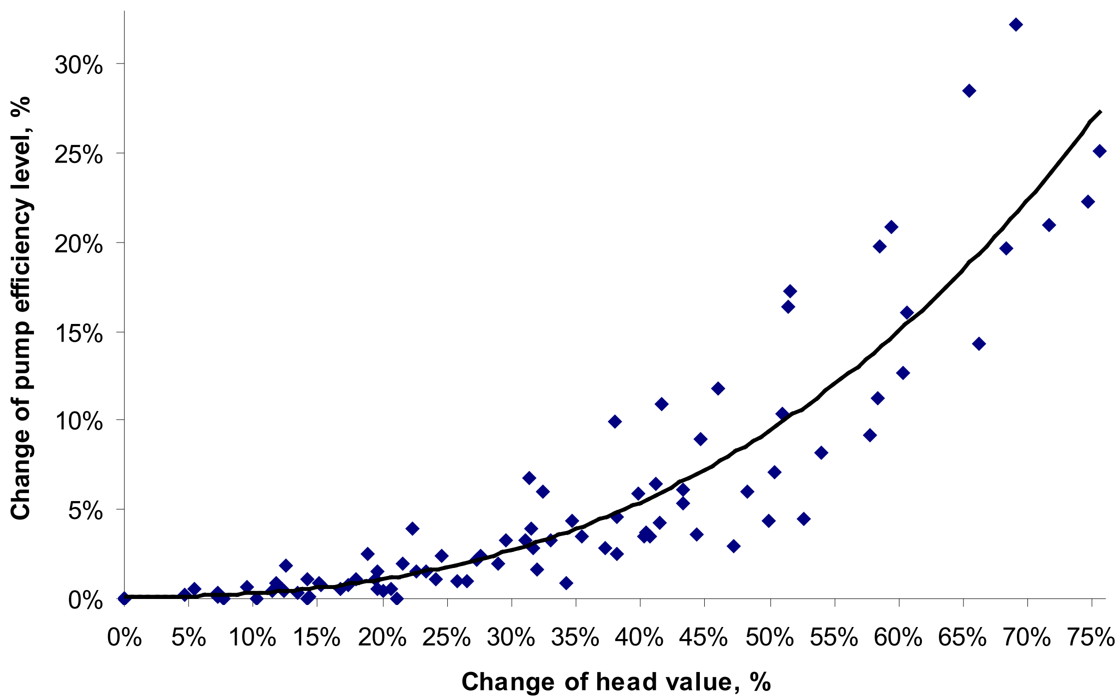

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Figure 4. **Change of centrifugal pump efficiency level at various deviations of head change from its nominal value**

differential pressure control mode) if the value of duty point remains invariable.

The possibility to define precisely the potential reduction of energy consumption of circulators in heating and cooling systems is considerably being decreased with the increase of deviation from the head value of current duty point at zero flow (Figure 3).

Evaluation of the change of the efficiency level of centrifugal pumps according to the location of the duty point

When the change of centrifugal pump efficiency level has been investigated at different values of head change from its nominal value (Figure 4), there has been derived the regression equation with the coefficient of determination (R^2) in the study.

The regression equation of polynomial trend type ($y=\alpha_0+\alpha_1*x+\alpha_2*x^2+ \alpha_3*x^3+ \varepsilon$) has been chosen.

$$\begin{aligned} y &= 0.398 \bullet x^3 + 0.1811 \bullet x^2 - 0.0032 \bullet x + 0.0012 \\ R^2 &= 0.8488 \end{aligned} \quad . \qquad (3)$$

In this equation (3), y represents the change of the pump efficiency level in % and x denotes the change of the centrifugal pump head from its nominal value at a constant value of flow in %.

It's possible to apply the equation (3) as a tool for the evaluation of the decrease rate of centrifugal pump efficiency level at different deviations from the head value of the best efficiency point (Giribone P. et al., 2006).

The possibility to precisely define the change of pump efficiency level is considerably being decreased with the increase of head deviation from the nominal head value of centrifugal pumps if the flow rate is kept constant.

Conclusions

In this research, it has been found that the reduction of annual energy consumption can be achieved up to 33% for circulators with variable speed motors in heating and cooling systems. This reduction of energy consumption is being achieved if the proportional pressure control mode is being applied in comparison with the constant differential pressure control mode. The deviations from the head value of the duty point at zero flow declines up to 60%.

The higher level of the deviation from head value of duty point at zero flow is, the higher level of energy saving is.

In the study, there is also shown that the decrease of pump efficiency level drops up to 3% if the head deviation from the nominal head value of best efficiency point at constant flow is up to 30%.

A slight decrease of pump efficiency level is observed if the deviation from the nominal head value is up to 30%. If the head deviation is above 30% from its nominal value, then the efficiency level of centrifugal pumps rapidly drops.

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EXPERIMENTAL INVESTIGATION OF HEAT CARRIER FLOW EFFICIENCY

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Abstract
In order to state the amount of heat energy produced by a solar collector or consumed by a heated floor, usually the heat transfer medium flow intensity as well as its inflow and outflow temperatures is to be measured. But these parameters are changeable during an operation. Therefore with a view to obtain more precise data, to automate the data acquisition process, the produced or consumed power and its character, the amount of produced or consumed energy at a certain period of time, the energy transformation ratio and other parameters, as well as to increase the attained data accuracy and credibility, a new heat carrier flow intensity meter has been developed and produced. Setting it with some data collecting device it is possible to determine the produced or consumed power as a function of time, and the produced or consumed heat energy in a certain time interval. The technical performance of the heat carrier flow metering system is given. Experimental investigation of the produced heat energy by the solar collector with a canal absorber, and the consumed heat energy by the heated floor panel, has been carried out using the newly developed method and some of the obtained results presented.
Key words: solar collector, panel, flow, efficiency, metering.

Introduction

When carrying out an experimental investigation of heat energy produced by a solar collector or consumed by the heated floor, it is important to state the efficiency of the heat source or heat consumer. Usually for this heat meters are used. For an experimental determination of the heat energy produced by a solar collector, a heat transfer medium meter usually is used, and the inflow and outflow heat carrier temperature has to be measured (Harcenko, 1991). The deficiency of this methodology is that it is hard to automate the process and to record the obtained data. It is possible to get only an average heat carrier circulation pump efficiency, but it is variable in time due to inconsistency of electric voltage, heat carrier temperature changes, circulation pump torque, and some accidental factors. For the scientific investigation of solar collectors and heated floor panels, where more precise data would be obtained, the measuring and data recording process has to be improved by using automated data metering and acquisition possibilities. In order to eliminate the mentioned shortcomings, to automate the data acquisition process and to increase the data accuracy and credibility, the heat carrier flow meter has to be equipped with a heat carrier flow intensity metering sensor and a frequency-voltage convertor. Therefore the objective of the research is to automate the data acquisition process and to increase accuracy and credibility of the obtained data. In order to attain the aim, the heat meter was equipped with the heat carrier flow intensity metering sensor and the frequency-voltage convertor. The outgoing from the convertor direct voltage, which numerically is directly proportional to the intensity of the heat carrier flow into the heat meter, was recorded into the data collector. By this the heat meter additionally was supplied by the heat carrier flow intensity metering and recording function.

Materials and Methods

At the experimental investigation of a heated floor or floor panel, more important parameters, which have to be stated, are the consumed power, the surface temperature of the heating element and its evenness along the surface. Designing the construction of the heated floor or floor panel, from the economic point of view it is important to minimize the heat losses, so that the coefficient of its efficiency is as high as possible. The evenness of the distribution of the temperature on the heating surface for the newborn piglets has to be about ± 1˚C. In order to establish the momentary power of the producing or consuming devices, it is necessary to know the heat carrier flow intensity, the heat carrier temperature flowing into and out of the device, as well as the heat carrier heat capacity. Then the power of a heat device can be calculated using formula:

$$P_h = g \cdot c_p \cdot (t_1 - t_2)\,, \tag{1}$$

where

- P_h – power of the heat device, W;
- g – intensity of the heat carrier flow into the device, kg s^{-1};
- t_1; t_2 – inflowing and outflowing heat carrier temperature, ˚C;
- c_p – specific heat capacity of the heat carrier (water $c_p = 4.18 \cdot 10^3$ J kg^{-1}°C^{-1}).

Table 1

Dependence of some water parameters on water temperature

T, °C	ρ, kg m^{-3}	c_p, kJ kg^{-1} °C^{-1}	T, °C	ρ, kg m^{-3}	c_p, kJ kg^{-1} °C^{-1}	T, °C	ρ, kg m^{-3}	c_p, kJ kg°C^{-1}
0	999.9	4.212	40	992.2	4.174	80	971.8	4.195
10	999.7	4.191	50	988.1	4.174	90	965.3	4.208
20	998.2	4.183	60	983.1	4.179	100	958.4	4.220
30	995.7	4.174	70	977.8	4.187	110	951.0	4.233

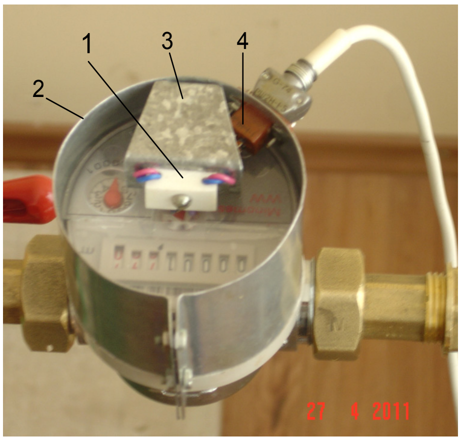


Figure 1. **Heat carrier flow intensity metering sensor**

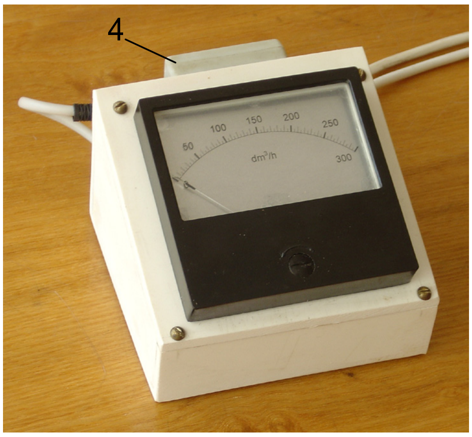


Figure 2. **Frequency-voltage convertor**

If the heat carrier circulation intensity g (kg h^{-1}) is known and if the water as the heat carrier is used, the heating device power can be calculated:

$$P_h = \frac{g \cdot 4.18 \cdot 10^3 (t_1 - t_2)}{3600} = 1.161 \cdot g \cdot (t_1 - t_2) \,. \quad (2)$$

If the produced heat energy is being accumulated, for instance, stored up in a hot water tank, the amount of produced heat energy can be calculated as following:

$$Q = m \cdot c_p (t_1 - t_2) \,, \quad (3)$$

where

Q – produced amount of energy, kJ;

m – heat carrier mass, kg.

If performing experimental investigation, where water is used as a heat carrier, it is important to consider the dependence of water parameters on its temperature. For the further calculations the necessary water parameters depending on water temperature in Table 1 are given (Михеев and Михеева, 1977).

Results and discussion

At the agency of the Latvia University of Agriculture Research Institute of Agricultural Machinery a device for solar collectors produced and heated floor panels consumed heat energy metering and recording device was developed for caring out the experimental investigation of heated floor panels for newborn piglets resting places. The device consists of two parts: self-made heat carrier flow intensity meter, and industrially produced data recording devices.

The heat carrier flow intensity metering sensor consists of a clamp 2, clenching the water meter (Fig. 1). In the clamp, a holder 3 is fixed. On the second end of the holder above the circumference of the heat meter's teethed rotor, a photo-electric convertor 1 in a plastic body is placed. In the clamp 2, a plug 4 is fixed, through which the sensor's plug by means of a cable is connected with frequency-voltage convertor 4 (Fig. 2).

On the front panel an indicator of the heat carrier flow meter is located, which limb is graduated in the range of 0-300 dm^3 h^{-1}. At the rear side of the body, a pocket 4 is made, where the data collector (HOBO Data Logger) is placed. The scheme of the electric circuit is located on a plate and installed into the plastic body of the frequency-voltage convertor.

In the right side of the frequency-voltage corrector's body, a frequency-voltage character line's corrector is installed. During the calibration of the device, the corresponding value of the heat carrier flow's intensity for the voltage convertor coefficient K has to be adjusted. The functional scheme of the device is shown in Fig. 3. It includes the circulation pump 1, the

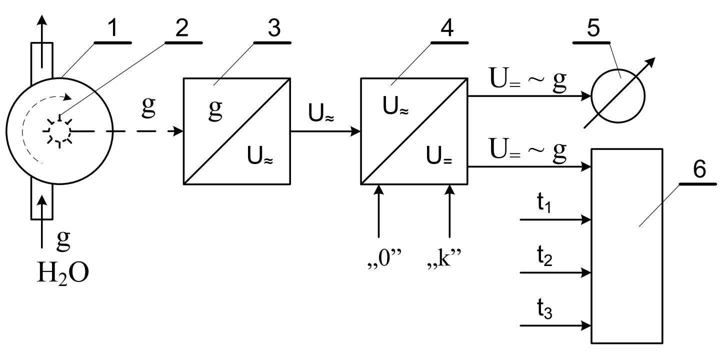


Figure 3. **Functional scheme of the device**

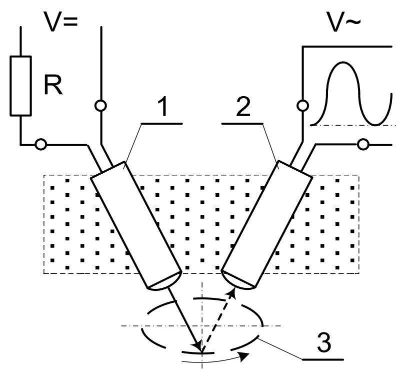


Figure 4. **Infrared irradiative diodes: 1 – VD1; 2 – VD2**

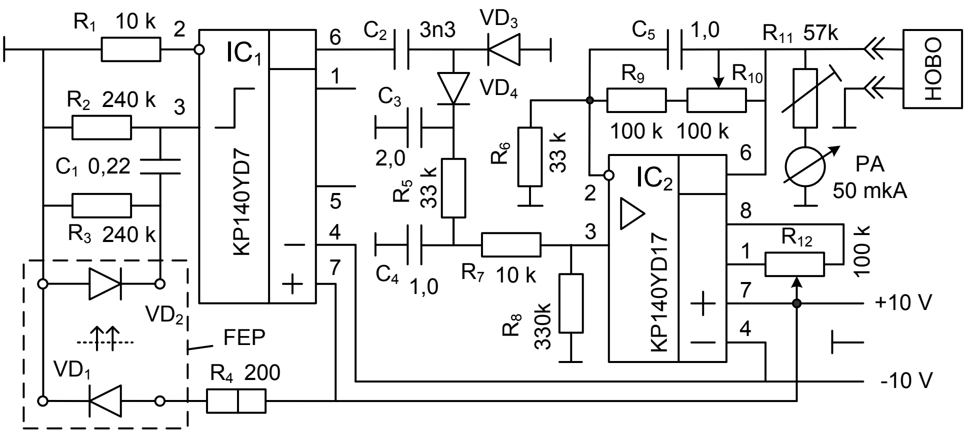
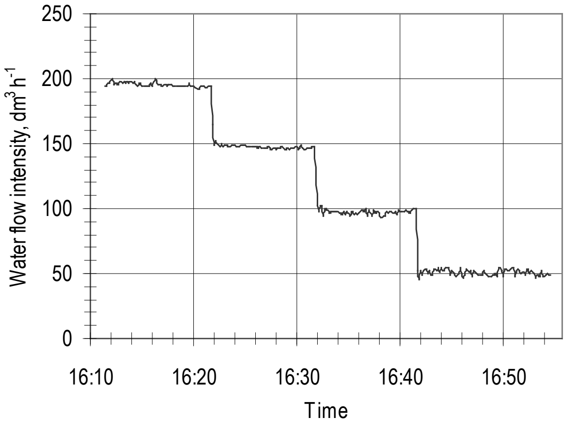


Figure 5. **Electric circuit scheme**

heat carrier flow turbine which, by means of magnetic clutch, is connected with a teethed rotor 2. Above the rotor, which is hermetically separated from the heat carrier space, the heat carrier flow intensity sensor with a photo-electric converter 3 is located, which itself is electrically connected with frequency-voltage convertor 4. To the frequency-voltage convertor 4 the flow intensity indicator 5 and data register 6, for instance, HOBO Data Logger U12-006, are joined.

The electric circuit scheme is given in Fig.5. The photo-electric convertor of the flow intensity consists of two infrared irradiative diodes: 1 – VD_1, and 2 – VD_2. They are placed on the division circumference of the teethed rotor 3 (Fig. 4). The diode VD_1 in series with the current restriction resistance R is connected to the electric voltage and produces the infrared radiation. When the radiation striking the teethed rotor spokes reflects from them on the diode VD_2, there the electric voltage is produced. If on the way of the infrared beams is a shrink between the rotor's spokes, from which the radiation does not reflect, the voltage on the diode VD_2 does not appear. The diode VD_2 through the condenser C_1 (Fig. 5) is connected to the incoming snap 3 of the operational intensifier IC_1. At the intensifier IC_1 outgoing voltage snap 6, an overcharge condenser C_2 is connected. To another snap of the condenser C_2, through the diode VD_4 the voltage accumulation condenser C_3 is connected. The condenser C_3 through the voltage fluctuation filter R5C4R7 is connected to the direct incoming snap 3 of the integral intensifier IC_2. The outgoing voltage snap 6 of the intensifier IC_2 is connected to the heat carrier flow intensity indicator PA, data register HOBO, and to the corrector R_{10} of the transformation coefficient K. To the intensifier IC_2 snaps 1 and 8, zero value adjustment corrector R_{12} of the transformation character line is connected. According to the functional (Fig. 3) and electric circuit (Fig. 5) schemes, the device is operating as following. When the heat carrier flows through the flow meter, its turbine is rotating and by means of the magnetic clutch turns the teethed rotor 3 (Fig. 4). If the fluid flow in the flow meter is constant, the turbine and rotor rotates continuously, and on the snap of the photo-electric converter diode's VD_2 appears and disappears the voltage. By the shape this voltage is like a sine curve (Fig. 4), which frequency is proportional to the teethed rotor rotation frequency and at the same time it is proportional to the intensity of the fluid flow

a



b

Figure 6. **Test of the flow intensity metering device in operation with the canal type solar collector „a", and its characteristic line at different flow intensity adjustments „b"**

frequency in the fluid flow meter. This voltage through the condenser C_1 is delivered to the direct incoming snap 3 of the operational intensifier IC_1, which when operation in the regime of the intensifier IC_1 at the exit 6 gives the meander shape voltage, by which the condenser C_2 charges and discharges into the condenser C_3. By each charge the voltage in the condenser C_3 increases. In order the voltage on the condenser C_3 remains proportional to the recharge frequency of the condenser C_2, and at the same time to the intensity of the fluid flow into the flow meter, simultaneously is taking place the condenser's C_3 discharge through the connected in parallel to it resistors R_5, R_7 and R_8. The recharge of the condenser goes as following. Condenser C_2 charges through the diode VD_3 from the feeding source, when on the operational intensifier's IC_1 outgoing snaps appears negative voltage (-9 V). During the charge it is disconnected from the condenser C_3 by the diode VD_4. When the voltage on the intensifier IC_1 outgoing snap 6 momentarily changes from negative to positive (+9 V), the condenser C_2 discharges into the condenser C_3 through the diode VD_4. The voltage from the condenser C_3 with resistors R_5 and R_7 is led on the operational intensifier's IC_1 correctors IC_2 direct outgoing snap 3. The voltage led to the snap 3 of the intensifier IC_2 decreases by the adjusted value of the transformation coefficient K=1+ (R9+R10)/R6. The heat carrier flow intensity according to the coefficient K value and parallel to the operational intensifier IC_2 outgoing voltage is adjusted by changing the value of the resistance R_{10}.

As a positive peculiarity of the device is relatively simple and fast control of its accuracy. For this it is necessary to take the time t_s of flowing out of 1 liter heat carrier at a constant regime of the device operation. Then the intensity of the heat carrier flow in $dm^3\ h^{-1}$, which has to be shown by the indicator and recorded by the data logger, can be calculated by formula

$$g = \frac{3600}{t_s}, \tag{4}$$

where

- g – amount of liquid flown out during the time t_s, dm;
- t_s – time of flowing out g amount of liquid g, s.

If the indication of the indicator does not coincide with the amount of liquid flown out of the device during the certain time, then for the indicator the value, obtained in the experiment, has to be adjusted using the correction coefficient K and by a screwdriver turning the axel in corresponding direction. In order to get the check-up result of high accuracy, instead of the register a high precision digital voltmeter has to be connected.

It has to be considered that 1V of voltage shown on the voltmeter has to correspond to the liquid flow intensity of 1000 dm^3 or 100 l per hour. According to face value (nominal), the intensity of liquid flow metered and recorded has to be in the range from 50 to 250 $dm^3\ h^{-1}$, because the data logger HOBO H08-006-04 is operating at the range of voltage from 0 to 2.5 V. The device after production has been tested at the solar collector with canal absorber (Ziemelis et al., 2007) (Fig. 6). The corresponding adjustment had been made according to the methodology given above with obtained data recording into the data logger HOBO Data Logger H08-007-02. The heat carrier flow intensity in the range of 195, 150, 100 and 50 $dm^3\ h^{-1}$ was adjusted according to the indicator of the device and digital multi-meter Escor 97.

The invented fluid flow intensity metering device (Putans et al., 2011) was used in a set with the temperature metering and recording system Pico TC-08 Thermocouple Data Logger, where for adjusting of the flow intensity meter with the system TC-08 self-made voltage devisor instead of Simple Chanel

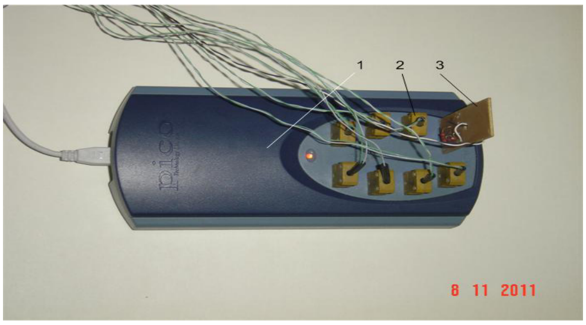


Figure 7. **Pico TC-08 Thermocouple Data Logger**

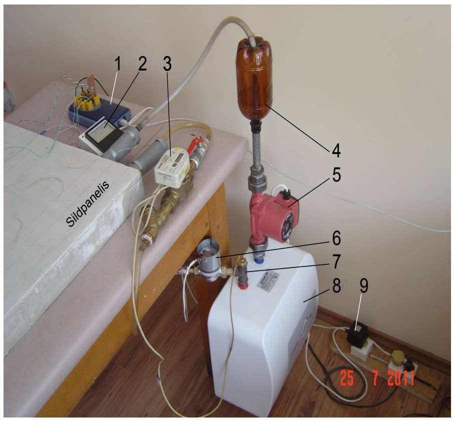


Figure 8. **Stand for an experimental investigation of the newborn piglets' floor heating panels**

Table 2

Flow intensity meter testing results

No	Results according to, l/h				Mean value	Max. deviation %
	flow Indicator	heat meter	PicoLog table	1litre - flowing out time		
1	150	153	153.3	150.5	151.7	± 1.09
2	109	112	110.6	106.3	109.47	± 2.6
3	44	45	43.8	42	43.7	± 3.4
4	31	31	31.4	29.3	30.67	± 3.4

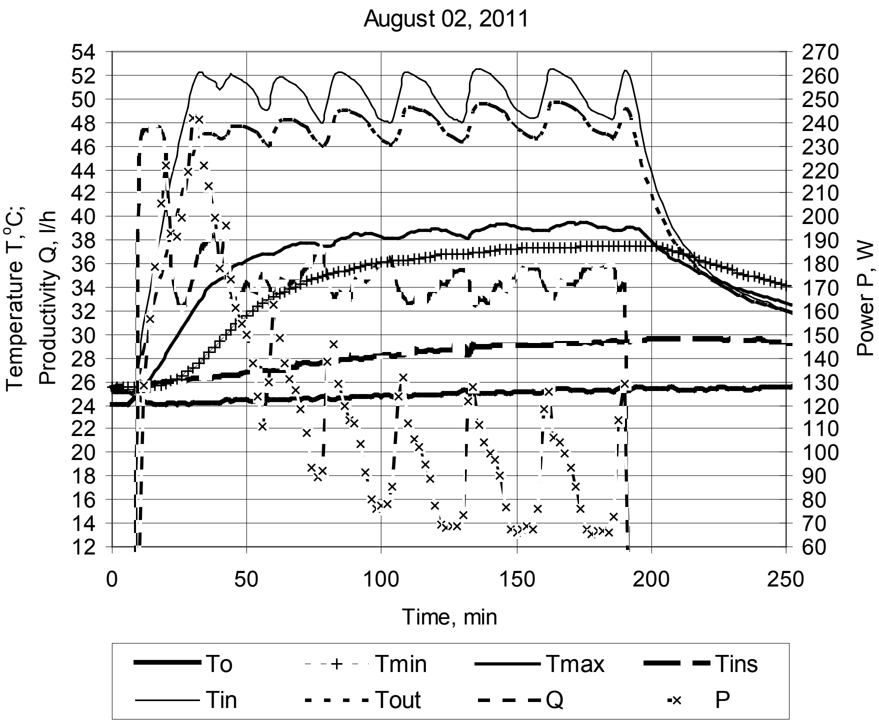


Figure 9. **Experimental results of the temperature distribution in the heated floor panel using the invented device:** To – surrounding air temperature, T_{min} and T_{max} – the lowest and the highest temperature on the panel's surface, T_{ins} – temperature inside the panel, T_{in} and T_{out} – inflow and outflow heat carrier temperature, Q – efficiency of the heat carrier circulation pump, P – heat power consumed by the panel.

Terminal Board is used. The Pico TC-08 Thermocouple Data Logger (Fig. 7) consists of a metering device TC-08 1, thermo-couple plug 2, and voltage devisor 3. To one metering device TC-08 it is possible to contact 8 thermo-couples (or a voltage source with U≤70 mV).

Pico type temperature metering-recording system is used together with the computer, in which the data gathering and processing system PicoLog is installed. The change of the data is going on using the USB interface.

For the experimental investigation of the new born piglets' floor heating panels, a special stand was developed (Fig. 8), which includes Pico TC-08 metering device 1, heat carrier flow metering indicator 2, heat meter M-CAL 0.6 compact 3, drainage vessel 4, heat carrier circulation pump 5, heat carrier meter and flow intensity sensor 6, temperature sensor plug socket 7, electric heat carrier heater (10 litres) 8, and heat carrier intensity meter feeding block 9.

Using the facilities given in Fig. 8, the test on comparing the data obtained by the heat carrier flow intensity meter with the data metered by the heat meter, PicoLog table data as well as the data gained by metering the time during which 1 litre of the heat carrier flew through the fluid consumption was carried out. The obtained results are presented in Table 2.

For the experimental investigation of the heated floor panels, the invented heat carrier flow intensity meter in the set of both the data recorder HOBO Data Logger H08-007-02 and Pico TC-08 Thermocouple Data Logger was used. As more perspective for the heated floor investigation has to be considered Pico TC-08 Thermocouple Data Logger system. Completing it with the worked out heat carrier flow intensity meter it is possible at the same time to meter and record the power and temperature of the heated panel practically in an unlimited number of points both on the panel's surface and inside its body. Example of the obtained results at heated floor panel's experimental investigation when the inflow water temperature is 50˚C in Fig. 9 is presented.

Conclusions

A special device for experimental investigation of heat energy produced by solar collectors or consumed by a heated floor has been developed, produced and tested.

The heat meter is equipped with a liquid heat carrier flow intensity metering sensor and a frequency-voltage convertor.

Using the invented heat carrier flow intensity meter in the set with the heat carrier flow intensity metering sensor and frequency-voltage convertor more precise experimental data have been obtained.

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IMPACT OF INDOOR TEMPERATURE ON ENERGY EFFICIENCY IN OFFICE BUILDINGS

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Abstract
Since most of energy in buildings is used for creation of healthy and comfortable indoor environment, lately an increased attention has been directed towards the optimization of operation of heating, ventilation and air conditioning (HVAC) systems. This paper presents graphic-analytical approach to investigate the impact of indoor temperature and relative humidity on energy efficiency. Thermodynamic analysis is performed using statistical data for outdoor air conditions in Latvia and recommended values of indoor air parameters for office buildings, prescribed by European standards in the field of indoor climate. The study shows that it is not economically viable to maintain optimal indoor air condition throughout the entire year, thus the allowance for deviation of temperature and humidity should be considered during certain periods, especially in summer. Results of this study could be further used for the improvement of building norms and regulations regarding the design and operation of HVAC systems.
Key words: energy efficiency, HVAC systems, temperature and humidity.

Introduction

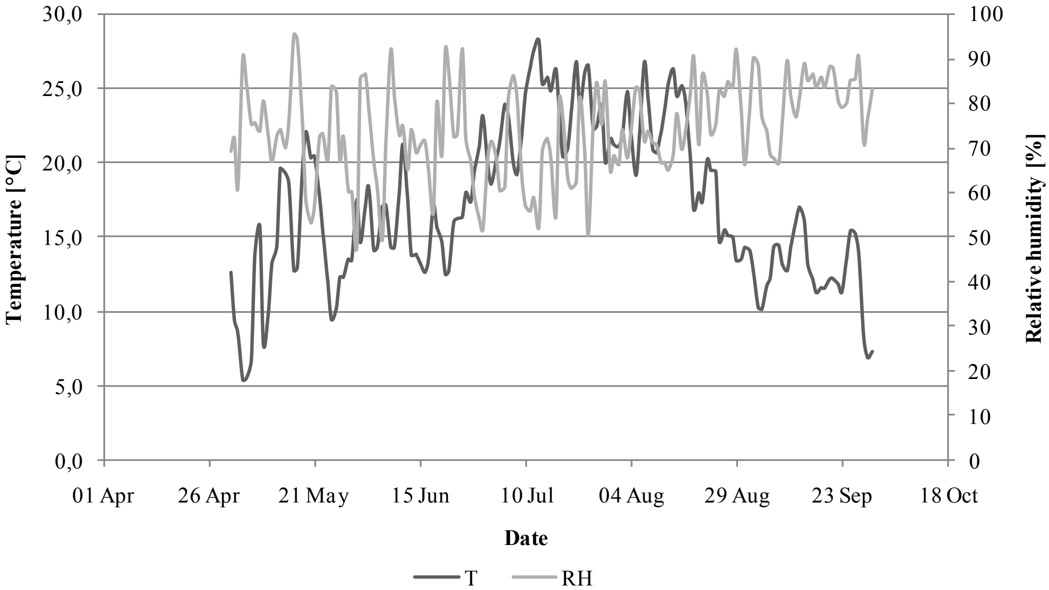
Nowadays most people in urbanized countries spend about 90% of their lifetime indoors, from which many spend their working hours in office environment. Therefore, it is important to establish a healthy, comfortable and productive work environment that the majority of building occupants will find pleasant and stimulating to stay and work in. ASHRAE standard (ASHRAE, 2004) recommends keeping temperature in the range of 23-26.0°C and relative humidity between 30% and 60% in office buildings. European standard 15251 (CEN, 2005) provides values of indoor temperature for different categories of indoor environment (I to IV). For office premises, the recommended operative temperature set-points are consequently 21.0°C, 20.0°C, 19.0°C during winter (heating) season, and 25.5°C, 26.0°C, 27.0°C during summer (cooling) season for categories I to III, respectively. Yamtraipat (Yamtraipat et al., 2006) investigated indoor temperature increase to 26.0°C and reported up to 36% electricity savings achieved by an increase of room temperature from 20.0°C to 26.0°C.

Outdoor climatic conditions itself are not sufficient to ensure the desired thermal comfort all year round; it is necessary to adjust to outdoor climate by using heating, ventilating and air conditioning (HVAC) systems for space heating and/or cooling. The type of HVAC system chosen will directly affect the airflow pattern within the building and consequently the indoor air quality and thermal conditions. Today one of the most commonly used air distribution methods in office buildings is conventional overhead mixing ventilation, where air is conditioned at the air handling unit (AHU), having a pre-heating coil, a cooling coil, and a secondary heating coil. Usually no humidifier is installed, that in its turn does not allow keeping optimal humidity throughout entire year. The combined effects of chosen air conditioning system and indoor temperature were studied by Fong (Fong et al., 2010) who found that variable air volume (VAV) system has energy saving potential from 5% for room temperature of 25.0°C to 33.2% for 30.0°C, and as opposed to VAV, constant air volume (CAV) system is not feasible when the room air temperature is above 27.0°C.

The following paper presents methodology for thermal energy calculations using graphic-analytical approach, and an example of its application analyzing statistical outdoor parameter data for Latvian outdoor conditions. The similar approach has been already used by Borodinecs (Borodinecs et al., 2007), investigating different ventilation operation regimes for dwellings. However, the paper was limited to graphical representation and no mathematical model was developed.

Materials and Methods

A mathematical model for thermal energy calculation is performed for the AHU having a pre-heating coil, a cooling coil, and a secondary heating coil. The AHU configuration considered in this paper has no humidifier and neither a heat exchanger. Power necessary to condition (heat or cool) outdoor air was calculated using most common psychrometrics equations and a h-x diagram. Only transmission heat losses were considered, thus infiltration and ventilation heat losses were not included in calculations. Effects of wind speed and solar radiation were also disregarded.



Source: Latvian Environment, Geology and Meteorology Centre (LEGMC, 2011)

Figure 1. **Outdoor temperature and relative humidity during the period May-September 2010**

The thermodynamic analysis is performed using statistical data for hourly outdoor air conditions (temperature and relative humidity), measured at a meteorological station in Riga (Latvia) during the period of May-August 2010, when both heating and cooling of air would be required. The Microsoft Office work package Excel was used to process statistical data of outdoor conditions. It has been decided to round up temperature by 0.5°C and humidity by 10% to find out the frequencies of particular temperature and relative humidity, expressed in hours.

Normally, in office buildings people work between 08:00-17:00 and thus in this example it was assumed that an office building is conditioned 12 hours daily, i.e. from 07:00 to 19:00.

Results and Discussion

Mathematical model development

Heat flow in a heating or cooling coil at the AHU is expressed as the total transmission heat loss subtracted with heating or cooling capacity to be covered by buildings' main heating/cooling system, as shown in equation (1).

$$H_t = \sum_i U_i \cdot A_i + \sum_k \psi_l \cdot l_k - H_{heat(cool)} \quad (1)$$

where H_t is the specific transmission heat loss (WK^{-1}), U_i is the heat transfer coefficient (Wm^{-2}K^{-1}), A_i is the surface area (m^2), Ψ_k is the linear thermal transmittance (Wm^{-1}K^{-1}), l is the length of thermal bridge (m), and $H_{heat(cool)}$ is the heating or cooling capacity to be covered by buildings' main heating/cooling system other than ventilation (WK^{-1}).

Supply air temperature (equation 3) can be found from equation (2).

$$H_t = m_a \cdot c_p \cdot (t_r - t_s) \quad (2)$$

where m_a is the mass flow rate of air (kgs^{-1}), c_p is the specific heat capacity of air (Jkg^{-1}K^{-1}), t_r is the desired room temperature (K) and t_s is the supply air temperature (K).

$$t_s = t_r - \frac{\sum_i U_i \cdot A_i + \sum_k \psi_l \cdot l_k - H_{heat(cool)}}{m_a \cdot c_p} \quad (3)$$

The specific thermal (heat) energy for conditioning of air can be then expressed as in equation (4).

$$E = \sum_i m_a \cdot (h_{2,i} - h_{1,i}) \cdot \sum_{t=-30}^{40} \sum_{\varphi=0}^{100} n_{t,\varphi} \quad (4)$$

where E is the specific heat energy necessary to condition the air (kWh), h_2 and h_1 is the enthalpy before and after a coil, respectively (kJ/kg); h=f(t,φ) and is found from the h-x diagram, n is the hours (h) with specific outdoor temperature and relative humidity.

Outdoor air conditions

Outdoor air conditions (temperature and relative humidity) in Latvia, calculated as daily averages for the period May-September 2010, are presented in Figure 1.

The outdoor temperature varied between 5°C and 30°C, reaching its highest values of about 27-28°C in mid-July. May and September months

Table 1

Frequencies of outdoor temperature and relative humidity combinations, expressed in hours

Relative humidity [%]	Temperature [°C] 4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0	10,5	11,0	11,5	12,0	12,5	13,0	13,5	14,0	14,5	15,0	15,5	16,0	16,5	17,0	17,5	18,0
0-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20-30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	1
30-40	-	-	-	-		-	-	-	-	-	-	-	-	1	-	-	2	-	1	3	1	3	1	9	4	4	6	3	10
40-50	-	-	-	-	1	-	-	-	-	-	1	2	5	3	3	1	5	-	-	6	3	9	8	11	9	15	22	16	9
50-60	-	-	-	-	-	-	2	-	2	2	2	3	3	2	3	3	7	3	5	13	14	29	14	17	13	11	9	9	8
60-70	-	-	-	-	-	2	-	4	1	-	5	8	3	1	2	7	7	11	15	15	21	18	17	22	7	5	7	14	14
70-80	-	1	1	2	6	7	3	2	3	6	-	1	-	2	5	5	15	17	14	27	18	8	25	14	6	8	12	4	13
80-90	1	1	6	5	1	1	-	2	1	8	2	5	8	7	10	15	14	25	6	15	17	19	15	8	5	12	4	4	6
90-100	-	-	-	-	-	-	-	-	-	-	2	3	-	-	-	1	8	4	3	4	2	-	1	-	3	1	5	1	1

Cont. Relative humidity [%]	18,5	19,0	19,5	20,0	20,5	21,0	21,5	22,0	22,5	23,0	23,5	24,0	24,5	25,0	25,5	26,0	26,5	27,0	27,5	28,0	28,5	29,0	29,5	30,0	30,5	31,0	31,5	32,0
0-10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10-20	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20-30	1	1	1	-	-	-	-	-	-	-	2	1	1	1	-	-	1	-	-	-	-	-	-	-	1	2	1	-
30-40	1	3	4	5	6	5	12	5	1	3	3	9	9	11	8	3	3	5	5	2	1	7	11	7	6	4	6	1
40-50	4	3	6	9	9	5	9	9	8	12	11	14	17	12	11	5	9	8	8	5	7	8	4	8	4	5	7	3
50-60	12	9	4	11	21	18	16	22	21	15	9	9	5	5	5	10	8	14	11	5	7	6	2	4	2	2	-	-
60-70	18	15	30	14	10	18	10	11	8	6	15	9	9	10	13	11	10	10	7	7	1	2	1	-	1	-	1	-
70-80	9	13	10	12	11	12	8	6	6	10	5	9	9	9	2	1	1	2	-	-	1	-	-	-	-	-	-	-
80-90	3	3	3	3	6	3	5	4	3	11	2	2	1	1	1	-	1	-	2	1	2	1	-	1	1	-	4	-
90-100	1	2	4	3	4	1	-	-	-	1	-	1	-	-	2	-	-	1	1	1	1	-	-	-	-	-	-	-

0-5 5-10 10-20 20-30

Source: Latvian Environment, Geology and Meteorology Centre (LEGMC, 2011)

were rather cold, with a temperature decrease of up to 5°C. According to Figure 1, there was a need to cool outdoor air in July and August months, when the temperatures were consequently the highest.

The average relative humidity was 75% ± 10%. It was the most humid in May, with a relative humidity reaching 95%. Combinations of temperature and relative humidity, expressed in hours, calculated for 07:00-19:00 regime and corresponding to the duration of particular conditions, are given in Table 1.

During the period May-September 2010, most of time the temperature was between 12.5°C and 23.0°C, and the relative humidity 40-80%. The most frequent (30 hours) combination of humidity and temperature was the temperature about 19.5° and the humidity between 60-70%. There has rarely been a need to humidify the outdoor air. Data provided in Table 1 could be further used for economic evaluations regarding the necessity of conditioning the outdoor air. For example, when making decisions whether to keep a desired room set-point or allow it to deviate during certain 'extreme' outdoor conditions, which last just a couple of hours.

The most frequent combinations of temperature and relative humidity in Latvia during the investigated period May-September 2010, as well as possible working regimes of ventilation system, presented on the h-x diagram are shown in Figure 2.

For AHU configurations studied in this paper, one can generally distinguish between three main regimes of operation of ventilation system. When an outdoor temperature is below 20.0°C (Zone 1), through the process of air heating it is possible to achieve a desired supply air set-point, while the desired humidity levels cannot be controlled. In Zone 2, an outdoor temperature is above 20.0°C and a relative humidity is below 50% and once again, it is possible to achieve a required temperature set-point, but not the relative humidity. If the outdoor air conditions correspond to Zone 3, the desired set-points can be achieved, first by cooling of air, and consequent heating after the condensation process.

Using the previously developed mathematical model, as for an example, thermal energy consumption was calculated for a space of 100 m^2, with the fresh air supply of 3.6 kgs^{-1} per m^2 conditioned area. Three different supply air temperatures were

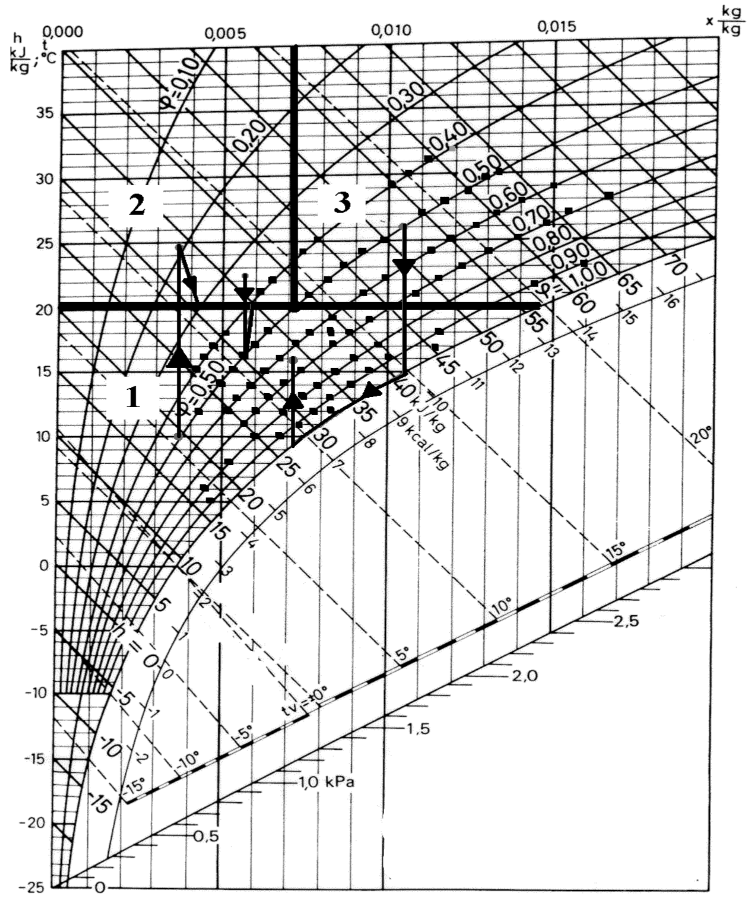


Figure 2. **Latvian climate parameters and ventilation system operation regimes in the h-x diagram**

investigated, i.e. 19.0°C, 20.0°C and 21.0°C (during the cooling period). It was found that thermal energy required to condition air to 19.0°C compared with 21.0°C was about 7% lower.

Conclusions

This paper presents graphic-analytical approach to investigate the impact of indoor temperature and relative humidity on energy efficiency. By use of an h-x diagram and statistical outdoor condition data, it is then possible to identify the air conditioning process zones, with the highest and lowest energy requirement to condition outdoor air. The most frequent AHUs used in office buildings do not have a humidifier, and the proposed method then enables investigation of, e.g. how many hours relative humidity is outside the desired comfortable range. For the cooling period, three different supply air temperature levels were studied, i.e.19.0°C, 20.0°C and 21.0°C. It was found that by increasing a temperature of supply air by 2°C (from 19 to 21°C), the energy consumption for cooling of outdoor air reduced by 7%. In addition, greater attention should be directed towards allowance of temperature fluctuations during certain periods of 'extreme' outdoor conditions that in its turn would lead to greater energy savings. The future improvements of the proposed model should be done, e.g. by inclusion of solar radiation data, infiltration and transmission losses, statistical data for outdoor conditions during longer periods.

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AIR HEATED SOLAR COLLECTORS AND THEIR APPLICABILITY

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Abstract
This paper describes the results of the investigation, the aim of which was to find new air heating solar collector constructions and easily accessible materials which may be used as absorbers. We tested the inflatable air heating solar collector construction. An inflatable solar collector gives good correlation with the air heating degree and radiation (r=0.93). This type of collectors is very sensitive to radiation changes, a response time is only about 1 minute. The given type of air heating solar collectors has a good efficiency, the efficiency coefficient is η =0.63. Absorber materials (seed boxes made of polypropylene, black colored energy drink cans situated on a steel-tinplate) are tested for room heating. Stationary air heating solar collectors for room heating are used when sun radiation exceeds 300 W/m^2, otherwise it is not effective or ambient air temperature is cooling room air. These collectors should be well insulated, especially if they are to be used in early spring, when ambient temperatures are low. These researches show the applicability of air heated collectors in drying agricultural production and in room heating at Latvia weather conditions.
Key words: solar collector, air, temperature, absorber.

Introduction

The Sun as an alternative energy source more and more widely is used in the national economy. The greatest advantage of solar energy as compared with other forms of energy is that it is clean and can be supplied without environmental pollution. So if more people used solar energy to heat the air and water in their homes, our environment would be cleaner. Over the past century, fossil fuels provided most of our energy, because they were much cheaper and more convenient than energy from alternative energy sources. The limited reserves of fossil fuels cause situation in which the price of fuels will increase as the reserves are decreased.

The Sun is the most powerful heat generator, which neither of the heat sources created by mankind can compete with. Yearly the earth is reached by the solar energy 15000 times more than the power industry of the whole world can produce. It means that only a tiny part of solar energy is being used for the sake of mankind.

We can use solar energy to heat and cool buildings (both actively and passively), drying production, heat water for domestic and industry use, heat swimming pools, generate electricity, for chemistry applications and many more operations.

The application of solar energy is completely dependent on solar radiation. An intrinsic difficulty in using solar energy is given by the wide variation in the solar radiation intensity. The availability of solar radiation depends not only on the location, but also on the season. Extreme differences are experienced between summer and winter, and from day to day.

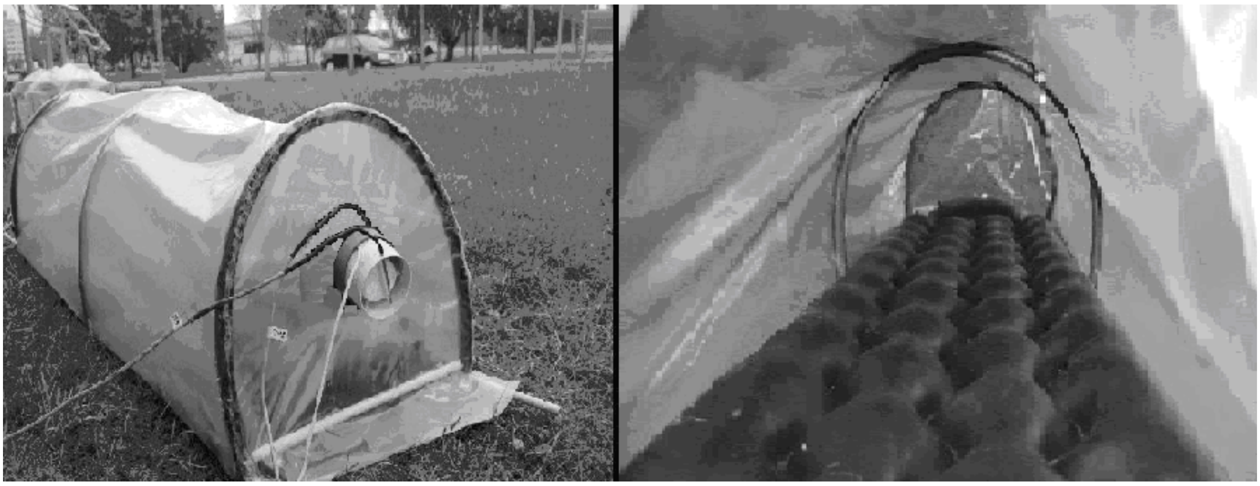
In general, solar air heaters are flat-plate collectors (FPCs), consisting of an absorber, a transparent cover, and backward insulation. The performance of solar air heaters is mainly influenced by meteorological parameters (direct and diffuse radiation, ambient temperature and wind speed), design parameters (type of collector, collector materials) and flow parameters (air flow rate, mode of flow). The principal requirements of these designs are a large contact area between the absorbing surface and air 'Kalogirou, S (2009)'.

The efficiency of air heating solar collector depending on collector covered materials (polyvinylchloride film, cell polycarbonate PC, translucent roofing slate), absorber (black colored wood, steel-thin plate etc.) and insulation of collector body with different air velocities in a collector was investigated '(A.Aboltins[a] et al., 2011; G. Ruskis et al., 2011; A. Aboltins[a], et al., 2011; A. Aboltiņs[b], et al., 2011; A. Aboltins, et al., 2009)'.

The air heating collectors can be used in two main directions for production drying and room heating (ventilation). Production issues through drying in the sun-warmed air are discussed a lot in works '(H.Y. Andoh et al., 2011; A. Aboltins[b], et al., 2011)'. We are exploring a variety of coating and absorbent materials to increase the air warm-up stage.

In case if you are using FPCs for room air heating, then they are mostly stationary, their efficiency is not only dependent on sun radiation, but also on a sun rays angle against collector surface. The sun rays fall under an angle to the collector plane (it means they fall under an angle to covered material) and they give more reflection.

We want to describe and to study some usages of created inflatable solar air heating collector in production drying and room heating using stationary air-heating solar collectors of different material absorbents.



Source: author's photo.

Figure 1. **Inflatable air heating solar collector (overview, inside).**

Source: author's photo.

Figure 2. ***View of the solar collector with cylinders of black coloured energy drink cans situated on the steel-tinplate absorber***

Source: author's photo.

Figure 3. **View of the solar collector with black polypropylene seed boxes absorber**

Materials and Methods

An aim of the experiment was to make an inflatable solar collector. The inflatable solar collector had simple constructions, easily usable and transportable. This type of collector is based on the inflated carcass with a good insulator of absorbent. As a coating material, polyethylene film has been used. For experiments, we used an inflatable air heating solar collector with dimensions: length 1.5 m, width 0.7 m and height 0.6 m (Fig.1). We used a fan with power 100 m^3/h for air ventilation in the collector.

Another part of our investigations devoted to the flat-plate collectors situated at wall in southward direction. The aim of our investigations was to compare different absorber materials and to make out their usability in air heating solar collectors for room heating and ventilation.

The *0.1x0.5x1.0* meters long experimental solar collector was constructed for research. As an absorber, there was used: a steel tinplate with cylinders of black coloured energy drink cans (Fig.2) and black seed boxes which were made of polypropylene (Fig.3). Air velocity in the experiments in the collector was v=0.9 m/s. In the collector, we used a fan with power 100 m^3/h and room space was approximately 80 m^3.

In the experiments, the collector cover material was polystyrol plate. This material has gained immense popularity due to such properties as safety, mechanical crashworthiness, translucence and high UV radiation stability. The cover material – a polystyrol plate reduced sun radiation by 12-15 %. The pyranometer was a solar radiation measuring instrument, which is used to measure total radiation.

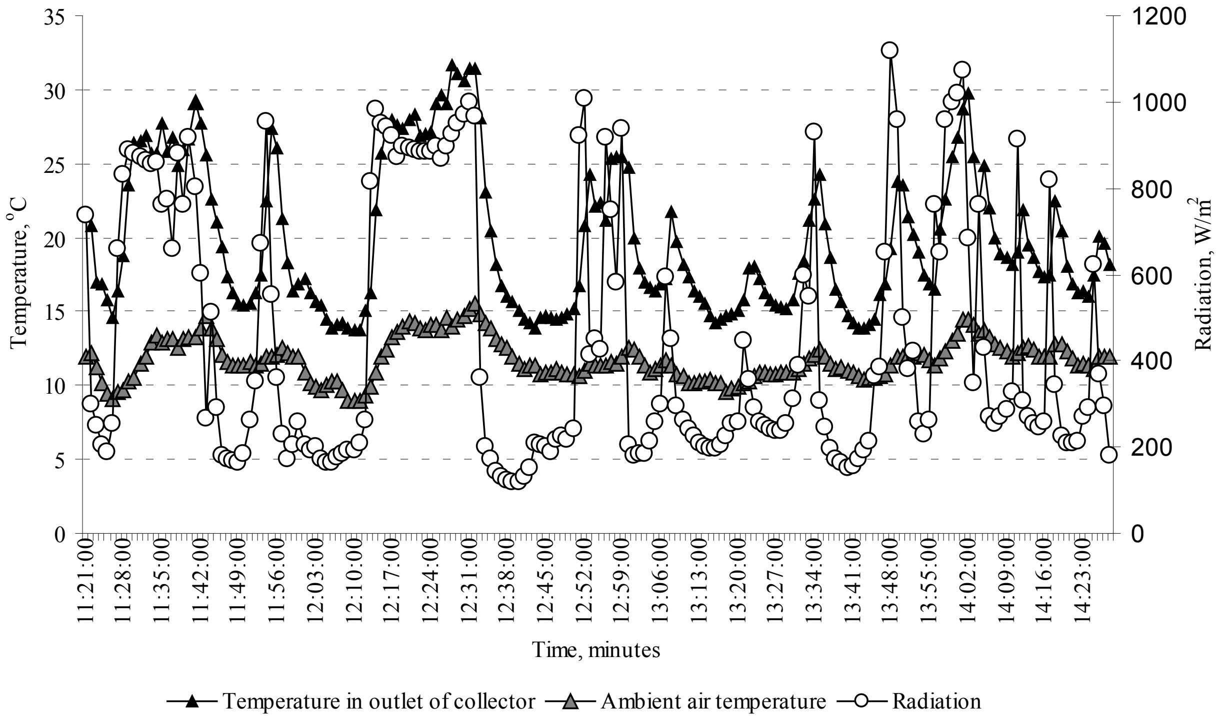


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Figure 4. **Inflatable solar collector's heated and ambient air temperatures comparing with sun irradiance in time**

Our task was to investigate a possibility to use the air heating solar collector for room heating. For this task, we used the collector built-in window. Through this collector window we ventilated room air. We measured room air, ambient air, and ventilated air temperature in the inlet and outlet of collector.

Experimental data are recorded by means of an electronic metering and recording equipment for temperature, radiation and lighting REG 'REG (2004)'. The pyranometer was the solar radiation measuring instrument.

The aim of our experiment was to compare and analyze the use of air heating solar collectors of different types for Latvian climatic conditions.

Experiments were made in the year 2011 from spring to autumn in different weather conditions at different ambient air temperatures and wind speed.

Results and Discussion

The data on the inflatable solar collector are shown in Figure 4. The experiment took place on 6 May 2011. Results show a very strong correlation between the solar radiation and the air warm-up stage. It should be noted that the air warm up in the collector quickly react to changes in radiation (clouds, shadows). Response delay time for the inflatable collector is approximately 1 minute, compared with the classical one it accounted for 5-7 minutes '(A.Aboltins[a] et al., 2011; G. Ruskis et al., 2011)'.

Using the obtained data and taking into account the warm-up delay time (1 minute), the relationship is obtained, which is characterized by the atmospheric air warm-up degree in the inflatable air heating solar collector, depending on solar radiation (Fig.5).

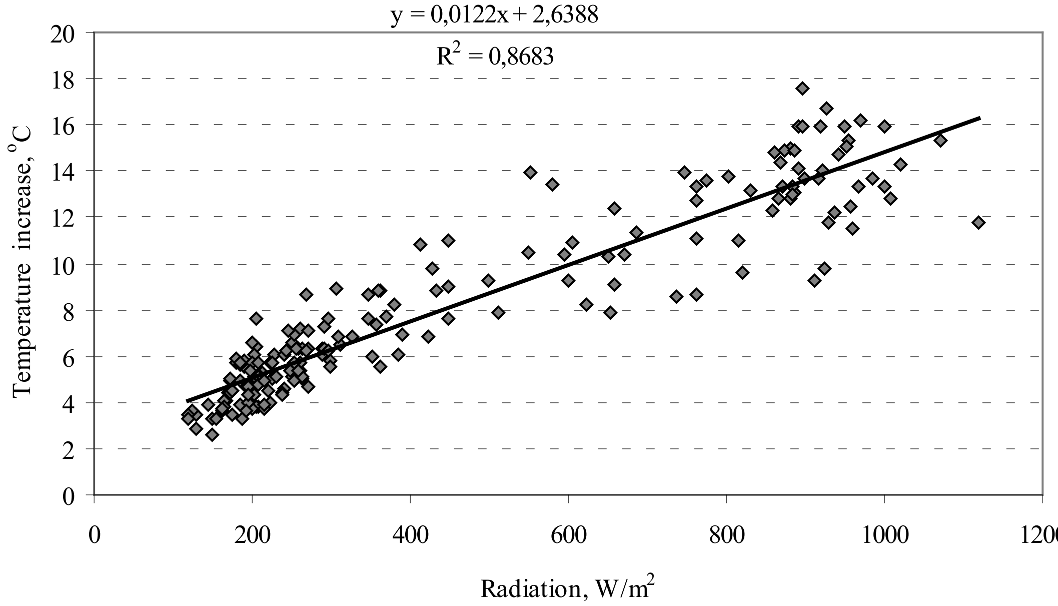
It should be noted the correlation coefficient (r = 0.93) is high under such rapidly changing sun radiation conditions.

We determined the efficiency of the solar collector, as prescribed in ASHRAE Standard 93 2003. The efficiency of the solar collector can be calculated by the following equation 'Clearinghouse (1994)':

$$\eta = \frac{m \cdot c_p \cdot (T_{fo} - T_{fi})}{S \cdot R_T} \qquad (1)$$

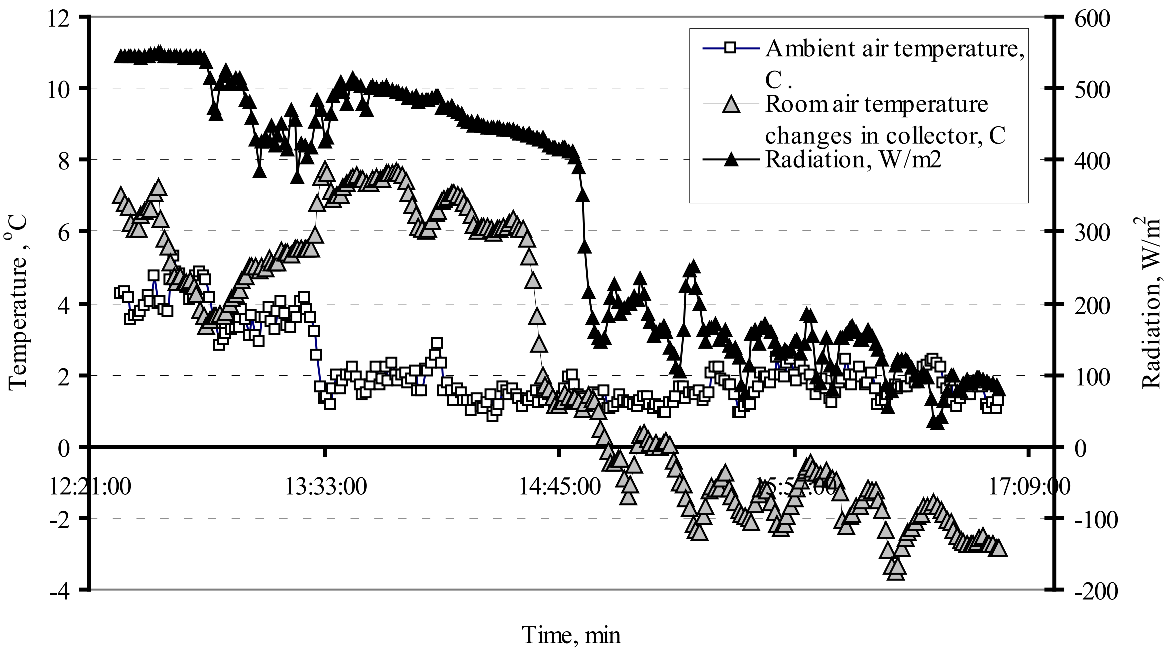
where

- η - efficiency coefficient of solar radiation converted into heat;
- m - mass flow rate of air, kg·s[1];
- c_p - specific heat, J·kg°C[1];
- S - area of solar collector, m²;
- R_T - global solar irradiance incident upon the aperture plane of collector, W·m²;
- T_{fo}, T_{fi} - outlet and inlet working air temperatures, °C.



Source: author's graph.

Figure 5. **Temperature increase in the outlet of the inflatable air heating solar collector comparing with sun radiation.**



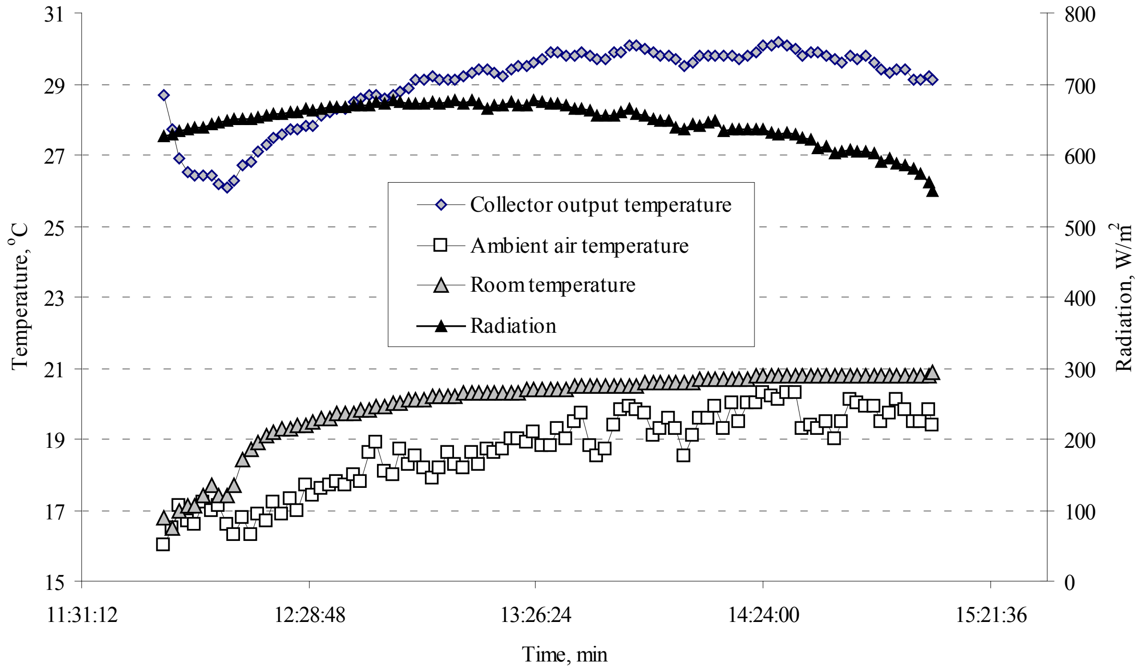
Source: author's graph.

Figure 6. **Room air temperature changes in the outlet of the collector (cylinders of black colored cans) and ambient air temperatures comparing with sun radiation in time**

With equation (1) were defined the effectiveness coefficient over the all experimental time using average working air temperatures and radiation. In our case, the inflatable air heating solar collector's efficiency coefficient η =0.63

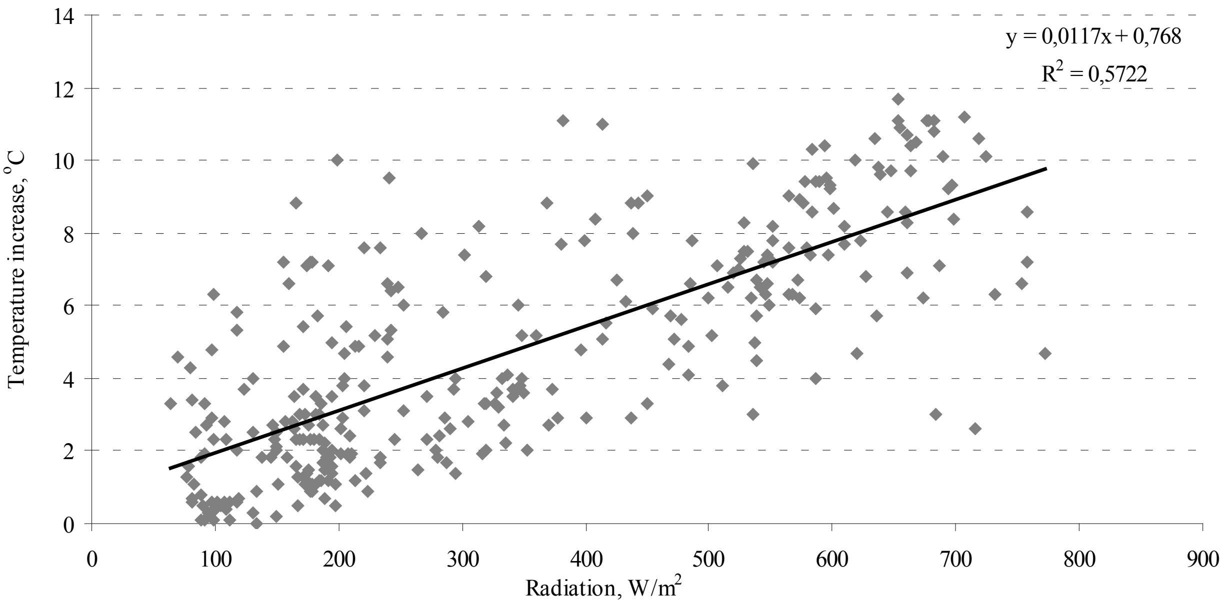
An issue is how to use the air heating solar collectors for room heating at Latvian climatic conditions. Experiments were performed with two types of absorbent materials (cylinders of black colored energy drink cans and with black polypropylene seed boxes).

As can be seen from the experimental 1 March 2011, solar radiation significantly affected the passing room air temperature warm-up stage (Fig 6). Experimental data show that due to little sun radiation constitutive air heating is not visible,



Source: author's graph.

Figure 7. **Room air, ambient air and collector outlet air temperatures (absorber material - black polypropylene seed boxes) comparing with sun radiation in time.**



Source: author's graph.

Figure 8. **Temperature increase in the outlet of the collector (absorber steel-tinplate with cylinders of black colored cans) comparing with sun radiation.**

but increasing sun radiation is raising the air heating level (Fig. 6).

When radiation is smaller than 300 W/m², the collector is not heating room air, because the absorbent cannot compensate heat loses influenced by atmospheric temperature. The air heating level is not highly dependent on ambient temperature, much more it is influenced by solar radiation and a horizontal irradiance angle of sunlight to the collector's surface.

We can see that the solar radiation changes significantly affect the passing air temperature. This effect does not happen instantly, but with a delay of 4-7 minutes. It should be noted that the un-insulated collector efficiency is highly influenced by wind speed, which cools the surface of the collector body.

Experimental data, which took place on 14 April 2011, with the black polypropylene seed boxes absorber are shown in Fig. 7. The room air passing through the collector heats up to 10 degrees up if the radiation greater than $600\ W/m^2$.

We are interested in room air temperature increasing in the outlet of the collector. We would like to know how sun radiation influences the air heating level for a stationary collector. Experimental data from 14 September 2010 show sun radiation and air temperature increase dependence in Fig. 8 (collector with an absorber steel tinplate with cylinders of black colored cans). Large data dispersion shows that the horizontal irradiance angle of sunlight to the collector's surface influences temperature increase which we ignored. The Sun's rays angle influence on the collector's effectiveness is shown at '(A.Aboltins[c] et al., 2011)'.

Conclusions

The inflatable solar collector is giving good results, an average ambient air temperature increase in experiments is 10.2C° and the max increase is up to 16 C°. This collector gives good correlation with the air heating degree and radiation (r=0.93). This type of collectors are very sensitive to radiation changes, response time is only about 1 minute. The given type of air heating solar collectors has a good efficiency, the efficiency coefficient is η =0.63.

The inflatable solar air heating collector is easy to make, operate and to derange its construction. It works well in Latvian climatic conditions.

Stationary air heating solar collectors for room heating are used when sun radiation exceeds 300 W/m^2, otherwise it is not effective or ambient air temperature is cooling room air. It should be noted that the collectors should be well insulated, especially if they are to be used in early spring, when ambient temperatures are low.

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HEAT TRANSFER IN EXTERNAL WALLS MADE FROM AUTOCLAVED AERATED CONCRETE

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Abstract
The paper is devoted to the analysis of heat and moisture transfer processes in walls made from autoclaved aerated concrete blocks. The paper gives theoretical calculation of heat and moisture transfer processes in autoclaved aerated concrete walls as well as is based on practical measurements. Analyzing experimental data, the model for heat and moisture transfer processes in walls made from autoclaved aerated concrete blocks was created and tested. The influence of drying process in autoclaved aerated concrete wall on the heat transfer process of the wall was also studied in this paper. The offered model of calculations takes into account the property of autoclaved aerated concrete as a porous material to enable the most accurate description of heat and moisture transfer processes in the external walls of enclosures in various exploitation conditions. In contrast to already known calculation models of the heat engineering properties of external walls, this model takes into account material internal structural changes, which consider the irregular structure of autoclaved aerated concrete, allowing for each separate diffusion process in layers.
Key words: material and construction.

Introduction

This paper presents theoretical research of modeling of the heat and moisture transfer processes in autoclaved aerated concrete walls. In the European Union, former USSR republics and the Baltic States there are held various researches, technological and practical activities dedicated onto the decision of the heat engineering problem of walling and materials. Although there are made many different experiments that give grounds for theoretical and practical basis of various heat engineering issues, the investigation of the heat and moisture transfer processes and the possibility to model them is still essential. It is important to evaluate not only a construction material, but also its production, construction and building prospects and creation of an effective modeling method. Thus, it is necessary to analyze the properties of autoclaved aerated concrete external walls using modern thermo-physical methods. When analyzing the processes in autoclaved aerated concrete, it is necessary to simulate them. It is especially urgent to investigate heat and moisture transfer processes in external walls made from autoclaved aerated concrete of new generation, both external and internal climatic factors, and the finishing material impact on them. The term autoclaved aerated concrete of new generation, in our publication, is understood as autoclaved aerated concrete blocks with bulk density 350 - 450 kg/m³, a dimensional accuracy of +/- 1 mm and forming joints in wall with glue mortar.

Structure of model and algorithm

Using the theoretical model and experimental data, a simulation of moisture migration and heat transfer processes for an exterior wall of aerated concrete of new generation as well as an analysis of the results of the calculations were made (Vilnītis M., Noviks J., Gaujēna B., Paplavskis J., 2010). During the period from March 2009 till May 2011, moisture of the block wall of aerated concrete of new generation, in terms of weight, decreased from 24% to 6.2%; experimental (Тамм Ю., Йыгиоя Э., 2006) data are shown in Table 1.

Data, given in Table 1, on the aerated concrete walls' drying can be described by the following equations:

$$Y(t) = 22.57\exp(-0.0017t) \tag{1}$$

$$Y(t) = 24.02 - 0.0456t + 3\times10^{-5}t^2 \tag{2}$$

where

$Y(t)$ – weight of moisture, shown in %,
t – time, shown in days

Experimental results and approximation curves are given in Figure 1.

Equation (1) describes the aerated concrete drying process as a relaxation in a constant time period, which is equal to approximately 590 days. Taking into account that by increasing the time of drying, the main target for humidity is to be balanced, we are recommending the equation (1) to be replaced with following equation (3):

$$Y(t) = 5.0 + 20.13\exp(-0.0033t) \tag{3}$$

Figure 2 shows that equation (1.3) can be used both in the start of the drying process of block and for the longer time intervals.

Table 1

		Moisture in terms of weight, %		
Date	Amount of days	South side	North side	Average
17.03.2009	0	25.5	22.2	23.9
19.05.2009	63	21.6	21.4	21.5
05.09.2009	172	17.4	15.4	16.4
31.10.2009	228	17.2	14.6	15.9
17.03.2010	365	12.1	13.3	12.7
18.05.2010	427	8.4	8.5	8.5
28.08.2010	529	9.2	7.1	8.2
12.03.2011	725	8.8	6.3	7.6
08.05.2011	782	6.4	6.1	6.2

Source: made by the authors

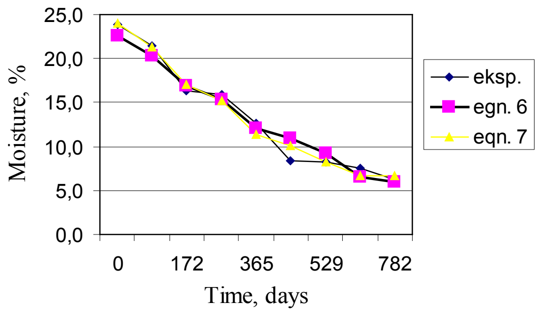

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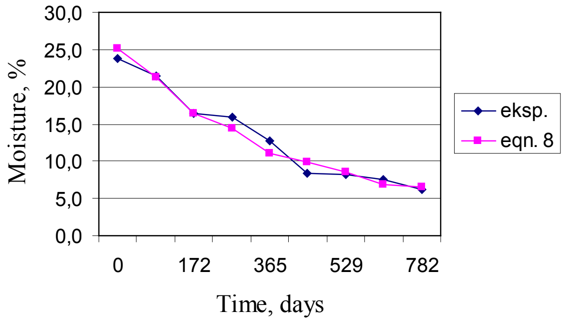
Figure 1. **Daily moisture changes in the exterior wall of aerated concrete of new generation**



Source: made by the authors

Figure 2. **Daily moisture changes in the exterior wall of aerated concrete of new generation**

But approximation (2) corresponds to the relaxation process with constant time $\tau_{saus.}$ which is approximately 300 days or 7200 hours. Balancing between a constant time period and steam permeability coefficient 0.23 (MHG / (m • h • Pa), a square meter of 375 mm thick walls of aerated concrete of new generation with a specific weight of 400 kg/m3 weighs ~ 150 kg. So, 20% of weight of moisture is that part which evaporates during the drying process. This water mass is about 30 kg. So, in 7200 hours the humidity in the form of vapor with a 30 kg mass will pass through the half of wall thickness (375/2 mm) with the vapor pressure which is equal to 3.4 Pa (0.026 mm Hg). At a room temperature of 20°C where water vapor pressure is up to 20 mm Hg (Кошкин Н. И., Ширкевич М. Г., 1960), unbalanced relative humidity with a size of only 0.1% relative humidity would make a sufficiently significant pressure drop, which approximately in 7200 hours would dry an aerated concrete block.

It is clear that the high aerated concrete material vapor permeability is essential for an outer wall in its drying process, where the plaster noticeably does not hold moisture of the material on the top, and between the inner and outer walls of the plane there is a slight drop in pressure. For example, in a building with a height of 4 m (up to the roof eaves), the inner room and outdoor temperature difference is 20°C, air pressure in the room (floor level) will differ from the outside pressure by 3.5 Pa (Фокин К.Ф., Табунщиков Ю.А. & Гагарин В.Г., 2006), which is virtually equal to the above estimate of the pressure. This means that the internal space and outdoor air temperature difference may cause a pressure drop that is sufficient to aerated concrete moisture vapor transmission to ensure clearance from the wall in about a 300-day period.

As a further factor, the pressure drop of the wind will be evaluated, which allows to «ventilate» connected pores in aerated concrete. In the case of wind speed of 5 m/s, wind pressure, which is calculated using the Bernoulli formula (Перехоженцев А., Григоров А., 2006), will be about 16 Pa, but if speed is 2 m/s - 2.6 Pa. This means that even a slight breeze to the building walls pressure (proportional to the square of wind speed), which is sufficient ventilation of aerated concrete pores, affects the drying process.

As a last factor, we will examine aerated concrete block drying time if air flow is not vented in the pores and drying occurs only by moisture diffusion. At a temperature of 0°C and pressure 760 mm Hg, the water vapor diffusion coefficient in air is equal to 0.21×10^{-4} (m^2/s]) (Кошкин Н. И., Ширкевич М. Г., 1960). Diffusion process can be described by equation (1.4):

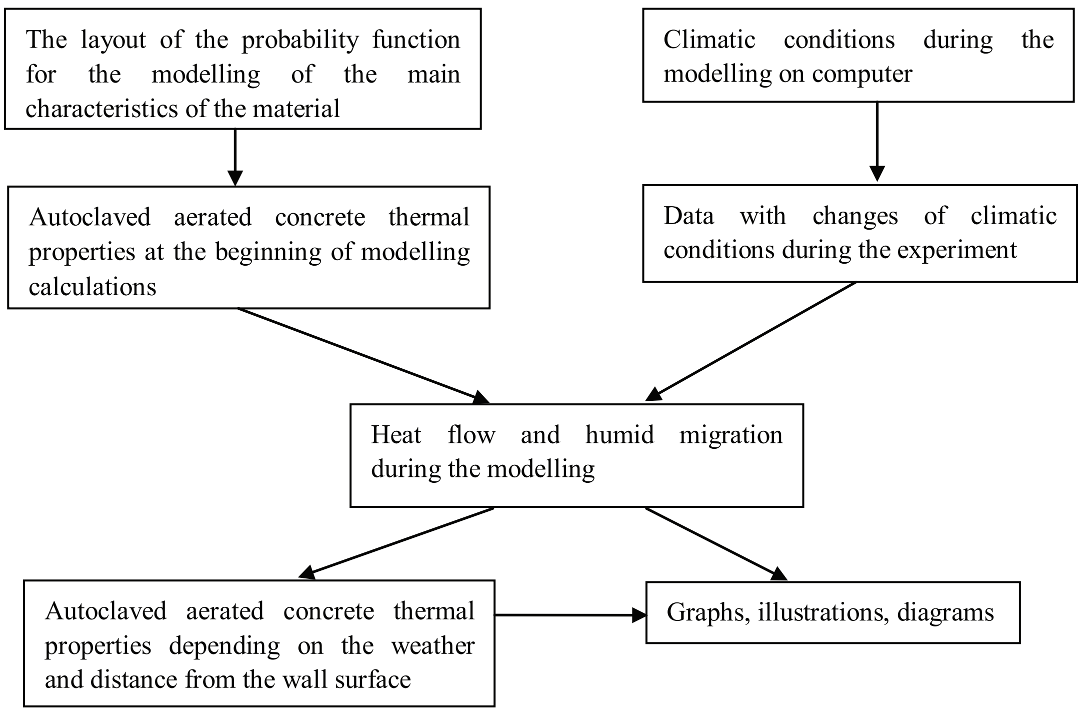
$$M = D\frac{\Delta C}{\Delta l}St \qquad (4)$$

where

- M - the mass, which is transmitted through the layer with the thickness Δl and area S of concentration difference ΔC at the amount of time t,
- D - the diffusion coefficient.

So, at a humidity of 100% and a temperature of 17°C, the water vapor concentration in the air will be 16 g/m3 in the inside part of block walls of aerated concrete of new generation. Assuming S = 1 m^2, Δl = 0.375/2 m or 0.19 m, one can obtain that in 1 second the diffusion process can move 1.77×10^{-6} kg in 1 day - 0.15 kg, and in 300 days, respectively, - 46 kg of water. The assessment carried out shows that the moisture transfer by diffusion is comparable to the moisture transfer with pore vapor permeability of the new generation aerated concrete. Thus, the model process and the computer program must take into account these two components for walls of the new generation aerated concrete during the drying process.

A program block scheme is shown in Figure 3. The program is designed for heat transfer and moisture migration modeling for autoclaved aerated concrete with the specific weight between 350 to 450 kg m^3, using combined analytical simulation method. For this purpose, autoclaved aerated concrete exterior walls can be conventionally divided into, small areas, each



Source: made by the authors

Figure 3. **Program block scheme**

of which provides an analytical relationship. In their turn, these, parameters for each of the areas are selected randomly, but according to the layout in the autoclaved aerated concrete material.6

Climatic conditions during the modeling on a computer, in the simplest case, can in one or several data file preparations, where indoor and outdoor air temperature, solar radiation, air humidity inside and outside is shown.

As a layout of the probability function for the modeling of the main characteristics of the material, a smooth layout, the layout of a normal, Poisson layout, or any other specific layouts may use in cases where it is necessary to accurately reflect the specific material. Properties (University of Latvia. Environmental and Technological Processes Laboratory for Mathematical Modeling, 2011.10.11.).

The calculations of modeling of autoclaved aerated concrete thermal properties, at the moment of the beginning of experiment, were performed with the statistical test method (the Monte Carlo method). Moreover, the size of the basic area in the modeling course should be corrected for cell sizes of material (40-80 cells per square centimeter).

The calculations of heat transfer and moisture migration in the course of modeling should select an appropriate pace so that the processes that are affected by daily fluctuations are estimated without significant errors (University of Latvia. Environmental and Technological Processes Laboratory for Mathematical Modeling, 2011.10.11.).

The data of thermal properties of autoclaved aerated concrete, depending on weather and distance from the wall surface, graphs, charts and illustrations are created, taking into account the possibility for comparison with the previously obtained experimental results.

Moisture migration and heat transfer process modeling

Analytical equations of elementary material parts with coordinates expressed with the vector x, includes the following variables:

$$\mu_3(\vec{x}),\ p_3(\vec{x}) \tag{5}$$

$$\mu_2(\vec{x}),\ p_2(\vec{x}) \tag{6}$$

$$\nu_1(\vec{x}),\ p_1(\vec{x}) \tag{7}$$

$$T(\vec{x}) \tag{8}$$

where μ_3(x) – humidity specific weight %; p_3(x) – saturated water vapor pressure attributable to closed pores; μ_2(x) – humidity specific weight %; p_2(x) – water vapor pressure attributable to open non-aerated pores; v_1(x) – relative air humidity %, p_1(x) – water vapor pressure attributable to open connected (aerated) pores; T(x) – temperature.

Taking into account the above-introduced markings, a moisture migration equation system for autoclaved aerated concrete material elemental parts can be written as follows:

$$\frac{\partial}{\partial t}\mu_3 = -D_{32}(\mu_{20}-\mu_2)\text{, if } \mu_3 > 0\text{, } \frac{\partial}{\partial t}\mu_3 = 0\text{, if } \mu_3 = 0 \tag{9}$$

$$\frac{\partial}{\partial t}\mu_2 = -\frac{\partial}{\partial t}\mu_3 - P_{10}^{-1}D_{21}(p_{20}-p_1) \tag{10}$$

$$\frac{\partial}{\partial t}p_1 = -D_{11}\frac{\partial^2}{\partial x^2}p_1 + V_x\frac{\partial}{\partial x}p_1 - D_{21}(p_1 - p_{20}) \tag{11}$$

where t – time; D_{32}(T) – the ratio that shows the diffusion of moisture between the autoclaved aerated concrete 2nd and 3rd 'layers'; μ_{20}(T) – layer final moisture saturation (about 10%); $p_{20}(\mu_2, T)$ – saturated water vapour pressure attributable to non-aerated open pores; D_{21}(T) – the ratio of moisture diffusion in the second layer of pores; D_{11}(T) - the ratio of moisture diffusion of air from open interconnected pores; V_x – the rate of the air flow in the direction of the connected pores wall surface; P_{10} – the ratio which depends on the number of open interconnected pores in autoclaved aerated concrete material elemental parts.

Without taking into account the complex and distinctive pore structure of autoclaved aerated concrete, size P_{10}(X, T) can be expressed as follows:

$$P_{10}(\vec{x},T) = \left(\frac{RT}{\mu_B}\right)\rho_B K_1^{-1} = \frac{\mu_в \rho_B}{\mu_B \rho_в K_1}P_0 \approx 6000P_0 \text{ if } K_1 \approx 0.2 \tag{12}$$

where R - universal gas constant; μ_A = 18 – water molecules in the molar mass; p_A – water density in liquid state; μ_a = 29 – air molar weight, p_a - air density; P_0 - atmospheric pressure.

Some material layers can be described with the following parameters:

$$D_{11}(\vec{x},T)\,,\; D_{21}(\vec{x},T)\,,\; D_{32}(\vec{x},T)\,,\; V_x(\vec{x},t) \quad (13)$$

$$\mu_3(\vec{x},t)_{t=0}\,,\; \mu_2(\vec{x},t)_{t=0}\,,\; \mu_{20}(\vec{x},T)\,,\; P_{10}(\vec{x},T) \quad (14)$$

where D_{11}(x, T) depends on the coordinates, taking into account the uneven pore structure (i.e. slightly less than the diffusion ratio of the atmosphere); D_{21}(x, T) depends on the coordinates, taking into account the average pore surface area of the material layer; D_{32}(x, T), P_{10}(x, T) and V_x(x, T) depends on the coordinates, taking into account different material properties, for which an air flow rate of material pores V_x (x, T) is proportional to the pressure difference between the outer walls surfaces.

In equations 9 and 10, values can be modeled using different distribution functions, for example, the simplest case D_0[1 - d_0ε(x)],)] where D_0 is determined, but d_0 size constant is not determined, while ε(x) is a randomly chosen value in the range [-1, +1] .]1) Moreover, in the first approximation this value depending on the temperature can be ignored, so that temperature effect is estimated with p_{20} (μ_2, T) and (albeit to a lesser extent) with μ_{20} (T).)

Taking into account special properties of a single layer of the material, humidity migration takes place not only in the perpendicular direction to external wall (relatively denoted as x direction), but also in the parallel direction (y and z). Therefore, equation 12 would be better written down in the following way:

$$\frac{\partial}{\partial t}p_1 = -D_{11}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)p_1 + +\left(V_x\frac{\partial}{\partial x}+V_y\frac{\partial}{\partial y}+V_z\frac{\partial}{\partial z}\right)p_1 - D_{21}(p_1 - p_{20}) \quad (15)$$

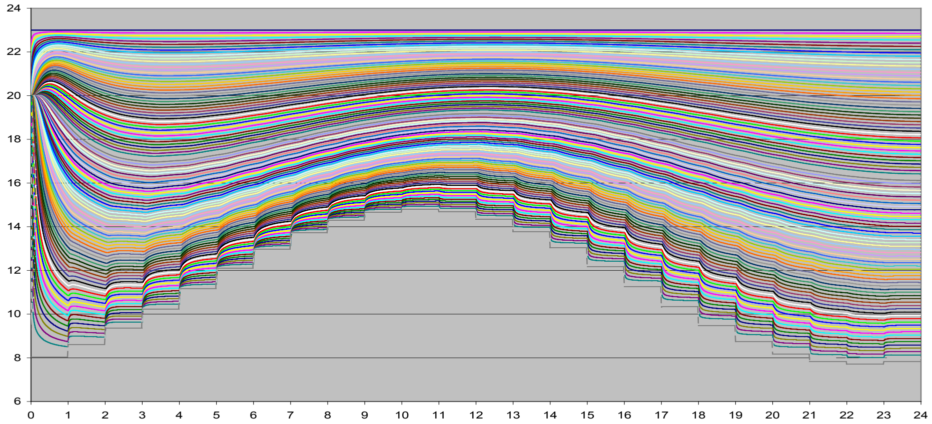
where the average speed of air flow in material V_y and V_z are equivalent to zero, they may differ from zero only in the light of the uneven structure of the small pores in the material layer. Moreover, there is executed the condition div (V) = 0, which means that the source of the air flow inside the material and the source of leakage (loss) are not decided.

Humidity transfer equations 9 – 11 and 15 should be supplemented with starting and boundary conditions and heat transfer equations. Drawing up heat transfer equations, the heat that arises from moister evaporation is not taken into account. It is possible, considering the fact that the autoclaved aerated concrete wall drying process takes place over several years while the temperature variation of wall thickness is diminishing in a few. However, drawing up the equations, the heat which arises from frozen water should be taken into account because the speed in which the water turns into ice (moves into another state) is not limited to humidity migration velocity in autoclaved aerated concrete block pores. It takes into account only the beginning of autoclaved aerated concrete exterior wall drying, stage, as the humidity level of autoclaved aerated concrete blocks after production is relatively high. While on the stage of construction, autoclaved aerated concrete is sufficiently dried, humidity distribution in the wall thickness is homogeneous and the outer surface of the bordering structure cannot freeze in winter period. In a simple case, it may be estimated with the value D_{32}(T), which depends on the temperature – if it is above 0°C, then the value is constant, if the temperature is below 0°C, then the value is zero (diffusion does not happen as the water is frozen).

The results of simulation

It can be concluded that a small time step allowable value of the direct calculation scheme is characterized by a large diffusion coefficient value. In real life, the diffusion coefficient, taking into account the liquid into the pores of the damp, is much lower. The diffusion equation solution "stabilized", taking into account some material "layers" the presence of distributed sources, and the allowable step at a time can be considerably higher. The direct scheme resulting solution stability will be further tested in experimental trials in the calculation. The above parabolic equation direct solution scheme can be improved with a stable, implicit scheme in use.

Figure 4 reported aerated concrete block layers with 1 mm distance, the temperature changes have been made during the calculation. Outer air temperature is modeled with a stepwise function - a step change in 1 hour step in solving the heat conduction equation has been chosen equal to 1 second. The figure shows the transition process, which takes about 3 hours, heat waves are also visible, the phase of the outside air temperature is lagging behind and the increase of the distance increases from the outer surface. Block thickness is 375 mm, the transition process will last longer than 3752 = 14 times and generally account for about 40 hours. This figure shows also the effective depth of the "high frequency" components of temperature fluctuation. 20 mm depth of the model stepwise temperature change seems already almost completely smoothed.



Source: made by the authors

Figure 4. **Calculation of a temperature in 1 day after installation of the block wall. The initial temperature of blocks is 20°C, room temperature 23 ° C, block thickness is chosen equal to 100 mm. This was calculated using the direct scheme with a time step of 1 second. On the x axis, clock time is marked, on the y axis - temperature in Celsius.**

Conclusions

A study shows that the moisture diffusion transfer in the form of magnitude is comparable to the moisture transfer of pore vapor permeability for aerated concrete of new generation, so when modeling these two components of outer wall of aerated concrete of new generation in the drying process must be taken into account.

Unlike the pre-positioning of exterior wall thermal properties of model-based calculations, in this case it is used in the structural material (internal) variable that is evaluated by the above material mixed layer interactions, taking into account different moisture migration processes in each of the layers.

Equations 5 – 10 and the relationship $D_{11}(T)$, $D_{21}(T)$, $D_{32}(T)$, $\omega_{20}(T)$, $p_{10}(\omega_2,T)$, $L(T,\omega)$, $c(T,\omega)$ represent a complex nonlinear system of equations that can be successfully used in the prediction of thermal process for aerated concrete of new generation in both time and space and in different functions for buildings, using a variety of finishing materials and modeling of climatic conditions.

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EVALUATION OF PARAMETERS OF RADIANT HEATING SYSTEMS

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Abstract

The majority of heating systems is accomplished by distribution system operating at high temperatures (90 -70°C). Main sources of heating used in Latvia are derived from non-renewable natural resources and wood-pulp or its derivatives. The use of more environment friendly technologies that allow minimization of energy consumption should play a significant role in Latvia's future civil engineering systems; nevertheless, the wider community is lacking trust and confidence in new technologies and understanding of the positive aspects of their use.

The installation of low-temperature heating systems is one of prospective ways to save energy and to reduce emissions. This kind of systems can be used for both: commercial and residential buildings. The low-temperature heating system can be installed in a wall or floor construction. This type can be preferable for building with high percentage of facade windowing, where usage of traditional heating system radiators is inconvenient from the indoor design point of view. In this case, blocks with heating systems installed into vertical or horizontal elements of the building envelope can be acceptable.

Thermal comfort is a benefit of low-temperature radiant heating systems. Additional sound insulation and high inertia factor that provides heating of the surfaces, even without initial phase of energy consumption, can be regarded as an advantage. Using theoretical base and program Microsoft Excel, the authors have made a calculation model to find dependences of several values for heating system with embedded heating elements into the building envelope. This study is aimed to demonstrate influence of the heat conductive device type and pipe spacing choice on the effective work of the system.

Key words: radiant heating systems.

POLICY OF THE EUROPEAN UNION IN THE FIELD OF RENEWABLE ENERGY RESOURCES IN THE CONTEXT OF COMMON POWER INDUSTRY POLICY

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Abstract
Policy of the European Union (hereinafter – the EU) in the field of renewable energy resources (hereinafter – RES) is relatively fresh. The first strategic goal concerning use of RES was defined by the EU just in 1997 suggesting that the share of RES in the total balance of primary energy resources should increase from 6% in 1997 to 12% in 2010. However, this so called 'primary' EU policy regarding RES was incomplete as attention was devoted to facilitating the application of RES with indicative objectives defined only in electric power supply and transport sectors. Lack of progress in achieving the indicative objectives and the need to promote the use of RES in all of the member states, not just some, served as a reason for developing a broader and more strict regulation in the EU policy for the field of RES, covering the prospect till the year 2020 so that the EU would achieve the renewable energy share of 20% by the year 2020. Here it is essential to recognize and understand, that the EU's strategic objective for the use of RES does not imply, that with such an approach the use of non-renewable energy resources would be limited in the foreseeable future. Namely, the EU's common power industry policy direction, which is focused on an integrated energy and climate change policy, in the foreseeable future, does not exclude the use of any energy resource. By supporting the use of non-renewable resources in the foreseeable future, preconditions are created for the promotion of a new industrial revolution to encourage the development of environmental technologies. It is important, because new and innovative environmental technologies can stimulate economic growth in various ways, while improving environmental indicators and conserving natural resources (it essentially helps to distinguish or separate economic growth from the impact on the environment).
Key words: power sector, energy resources.

Introduction

In the era of information technology, the use of energy resources has become an integral part of everyday life. For example, the European Environmental Agency states: 'Energy gives personal comfort and mobility to people and is essential for the generation of industrial, commercial and societal wealth'. But all of this has also negative features – energy production and consumption creates a significant strain on the environment. These impacts include the greenhouse gas (hereinafter – GHG) and air pollutant emissions, land use, waste generation and oil spills. This strain affects climate change, damages natural ecosystems and man-made environment, and has an adverse affect on human health (European Environmental Agency, 2011).

To a large extent, the negative characteristics of energy production and consumption stressed above are formed because in the result of various historical event interactions, the situation has evolved so that in the era of information technology the production processes of energy necessary for public purposes on a global scale is dominated by the use of fossil fuels (coal, oil, natural gas, etc.). For example, the European Environment Agency indicated that about 79% of the energy needs of the average European are met by fossil fuels. Around 13% comes from nuclear power and the remaining 8% comes from rapidly increasing renewable energy sources (especially wind, biomass and solar energy) (European Environmental Agency, 2011).

In this context, it is important to realize that the International Energy Agency predicts that in the foreseeable future the global energy demand will only grow. Consequently, regarding its terms, a situation emerges, in which mankind is simply forced to develop environmental technologies (including all technologies which are less environmentally harmful than respective alternatives) and the wider use of renewable energy resources (hereinafter – RES) (which are more environmentally 'friendly' than fossil fuels) in power generation systems, and introduce energy-saving measures. In addition, it is related not only to GHG emissions, which, by the intensive use of fossil fuels, can form in large quantities, but also to the commercial, legal and price uncertainty associated with the use of fossil fuels. Namely, the global demand for fossil fuels is growing, but its supply becomes less (at least the available relatively cheap supply), its extraction is becoming more expensive and more complicated because of troublesome geographical and geological conditions, hence the availability of energy production – more limited. Not of secondary importance is the fact that in the world the reserves of fossil fuel are distributed very unevenly – large amounts of the reserves are located in geopolitically unstable regions, and in most cases they are owned by state-run enterprises, which may not always react appropriately to free market forces (International Energy Agency, 2011).

In this particular research, the EU renewable energy policy in the field of RES, in the context of common power industry policy, is selected as the ***research object***. In other words, the object of research covers the mutual evaluation of the EU policy's direction in the field of RES and common power industry policy, where on the one hand it is the use of RES, but on the other – the use of non-renewable energy resources. This outlines the ***research subject*** – the study is delimited by focusing on the assessment of EU policy in the field of RES in the context of common power industry policy, mainly from a viewpoint covering the use of energy resources (renewable and non-renewable) for the prospect of a low-carbon dioxide emissions economy[1] by the year 2020.

The research aim: to evaluate European Union policy in the field of renewable resources in the context of common power industry policy.

The research tasks:

1. to analyse the European Union's policy in the field of renewable resources;
2. to describe the position of the European Union's power industry policy concerning the prospect use of non-renewable energy resource in a low-level carbon dioxide emissions economy.

Materials and Methods

The research is theoretical, developed in the year 2011, and the description of the object under research, both overall and between object parts, includes ***research methods*** such as analysis, synthesis and the monographic method. The research was done on the basis of research analysis carried out by academic and scientific staff (professional researchers), the European Union documents on power industry, as well as some Internet sources.

Results and Discussion

1. The European Union's policy in the field of renewable energy resources

Ever since the begging of the 1990's the European Commission (hereinafter – the EC) sought to introduce quantitative objectives on the European Union (hereinafter – the EU) level in order to increase RES in the final energy consumption of the EU. As an example, the ALTENER program can be pointed out, under which in the year of 1993 the EC proposed to double RES in the final energy consumption of the EU from 4% in the year 1991 to 8% in the year 2005. In later years, the established objective was ambitiously increased and in the year of 1997 'Energy for the Future: Renewable Sources of Energy. White Paper for Community Strategy and Action Plan' (COM (1997) 599 final) the first strategic objective concerning the use of RES in the EU was defined. This objective stated that the proportion of RES use in the EU's primary energy balance has to increase from 6% in the year 1997 to 12% in the year 2020. This decision was mainly due to the need to reduce the carbon dioxide emissions created by the energy sector, to support the promotion of a sustainable development concept in the EU, and to reduce the EU's growing dependence on fossil fuels, which was being imported from politically unstable regions outside the EU (European Commission, 2011).

The next planning document of EU power industry policy strategic direction, which was significant from the use of RES point of view, was developed in the year 2000. It was the 'Green Paper - Towards a European Strategy for the Security of Energy Supply' (COM (2000) 769 final). This policy's planning document specifically highlighted the EU's dependence on energy resource import. Recognizing the EU's large potential of RES, the 'Green Paper - Towards a European Strategy for the Security of Energy Supply' proposed the increase in the use of RES as the main policy's objective. At the same time, it was stressed that for the wider use of RES it was necessary to implement financial support and tax incentives because, compared to fossil fuels, RES is at a disadvantageous so-called 'start position' (Adelle, et al., 2011).

Strategic objectives for the use of RES in the 'Energy for the Future: Renewable Sources of Energy. White Paper for Community Strategy and Action Plan' was taken over by the EU with 'Directive 2001/77/EC on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market'. Its objective anticipated to increase the proportion of RES generated electricity in the final energy consumption of the EU to 22.1% by the year 2010. A similar objective, to the use of RES in the sector of electric power supply, was promoted in the year 2003 with regard to the transport sector – at least 5.75% of final fuel consumption of the EU in the year 2010 should be biofuel. This objective was included in 'Directive 2003/30/EC on the Promotion of the Use of Biofuels or Other Renewable Fuels for Transport' (Adelle, et al., 2011).

In the view of the 'Green Paper - Towards a European Strategy for the Security of Energy Supply' conclusions, that in the year of 1998 the cogeneration cycle had produced only 11% of the electricity consumed in the EU and set a goal to increase this figure to 18% by the year 2010, and one of the high-efficiency cogeneration criteria is the possibility to use RES, in the year 2004 'Directive 2004/8//EC on the Promotion of Cogeneration Based on a Useful Heat Demand in the Internal Energy Market and Amending Directive 92/42/EEC' was accepted (Adelle, et al., 2011).

The so-called 'primary' EU policy, with an emphasis focused on defining quantitative objectives for the use

[1] A 'low-level carbon emissions economy' is called an economy that produces only minimum greenhouse gas emissions in the atmosphere (especially concerning carbon dioxide). In the particular research this economy is examined form the power sectors view – use of energy resources to ensure low greenhouse gas emissions.

of RES, in the field of RES described above had to major drawbacks. First of all, the objectives for the use of RES in the member states were defined as indicative and not mandatory. Secondly, the indicative objectives for the use RES were only defined for the electric power supply and transport sectors. It resulted in a situation, where in the influence from the directives on cogeneration and energy efficiency, a gradual development of the market for heating and cooling sector was occurring. However, the use of RES in this sector grew relatively slowly, and at the same time the necessary progress towards achieving the use of indicative objectives for RES in the electric power supply and transport sector was not provided. Thus, for example, in the year 2004 in 'The Share of Renewable Energy in the EU' (COM (2004) 366 final) the EC concluded that even under the condition, when a reduction in electricity used by a building was achieved, defined by the requirements established in the field of energy efficiency, the final energy consumption of RES produced energy by the EU in the year 2010 would only comprise of about 18% to 19% (the strategic objective was 22.1%). In the statement 'The Share of Renewable Energy in the EU' (made by the EC) the amount of biomass use for electricity production was pointed out as the main reason for the significant deviation from the originally planned figures (European Commission, 2004).

To increase the use of biomass in the EU, in the year 2005 the EC developed one of the first action plans for the promotion of RES use – 'Biomass Action Plan' (COM (2005) 628 final). It defined the main activities focused on the development of bioenergy market (mainly on the establishment of market-based initiative for the use of biomass and the removal of market development obstacles) in order to increase biomass energy extraction from wood, waste and agricultural crops. This approach clearly demonstrated the important role of biomass in the EU power industry policy (European Commission, 2005).

In the result of the political and economic conflict between Russia and Ukraine, in January 2006, when Russia terminated their natural gas supply for the large part of the EU member states, the EU energy market suffered the most significant impact after the second oil crisis. An overall situation in the EU energy market in the year 2006 was very tense, emphasizing the need for an effective solution to the further development of EU power industry policy. Under these circumstances, in the year 2006 the EC published 'Green Paper. A European Strategy for Sustainable, Competitive and Secure Energy' (COM (2006) 105 final). In this policy document, the EC stressed that the EU has entered a new era of power generation, where RES will have an important role. It was noted that the EU would only achieve its full RES potential if there will be a long-term commitment to develop and use renewable energy (Adelle, et al., 2011).

As a reiterative confirmation that the EU's power sector has a need for a new policy that would focus on achieving the strategic objectives faster was the conflict between Russia and Belarus in January 2007. As a result, Russia had terminated the natural gas supply to a part of EU member states again. In the influence of this event, the European Council activated an attitude that there is a need for a more integrated and more legally binding power industry policy. The position of the European Council was based on two major considerations. First of all, if a member state does not address the common power industry problems of the EU, it affects other member states. Secondly, if problems arise outside of the EU, it can affect the EU as a whole. The new EU power industry policy was primarily related to such objectives as increasing the security of energy resource supply; ensuring the competitiveness of the EU economy; access to energy that the EU can afford financially; promotion of environmental sustainability and combating climate change (European Commission, 2008).

In January 2007, the EC published a comprehensive proposal complex dedicated to the power sector with the so-called EU 'Climate and Energy Package'. This package consisted of three ambitious initiatives which provided for the year 2020:

- a reduction in EU greenhouse gas emissions of at least 20% below 1990 levels;
- 20% of EU energy consumption to come from renewable resources;
- a 20% reduction in primary energy use, compared with projected levels, to be achieved by improving energy efficiency.

The initiatives, under the name of '20-20-20', were approved by the leaders of EU countries in March 2007. It should be pointed out that, having regard to all three so-called '20-20-20' initiatives, in March 2007 the country leaders of the EU had confirmed an integrated approach to climate and energy policy, based on specific and measurable objectives. By doing this, the EU committed itself to transferring to an economy characterized by low levels of carbon dioxide emissions and energy saving (Gubb and Hatton, 2011).

In January 2008, the EC published mandatory normative legal acts for the achievement of the so-called '20-20-20' initiative, and already in December of the same year the European Parliament (hereinafter – the EP) approved the EU's so-called 'Climate and Energy Package' in the first reading. The legislation for EU member states included in the package became legally binding in June 2009, when a set of legal texts for implementing the adopted measures by the EP in April 2009 were published in the Official Journal of the European Union (European Commission, 2010a).

With regard to the use of RES, the so-called EU 'Climate and Energy Package' include 'Directive 2009/28/EC on the Promotion of the Use of Energy from

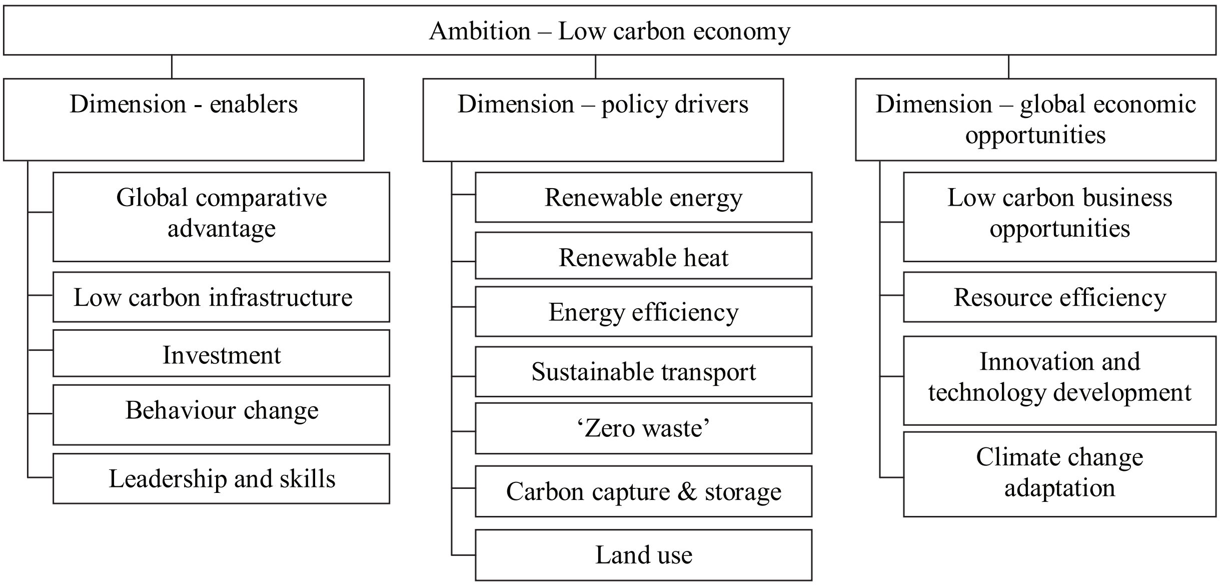
Renewable Sources and Amending and Subsequently Repealing Directive 2001/77/EC and 2003/30/EC'. This EU directive represents legally binding, rather than indicative objectives of the RES produced energy share in 2020 of gross final consumption of energy, and is the first attempt in EU power industry policy to create a comprehensive legal framework for promoting the use of RES in all key energy sectors – heating and cooling, electric power supply and transport sector. As the EC has stressed in the statement in 'Renewable Energy: Progressing Towards the 2020 Target' (COM (2011) 31 final), that the main reasons to change the political approach to field of RES use, were exactly the lack of progress in achieving the strategic objectives regarding the use of RES in the year 2010, and the need to promote the development of RES use in all member states, not just some (European Commission, 2011).

From the view of its terms, the position of the EC, in relation to the use of RES by 2020, can be seen as rational and reasonable. Namely, the only available fossil energy source of the EU that can limit the increasing dependence on oil and natural gas imports from unsafe third world countries is coal, so to some extent the EU is highly dependent on relations with energy resource suppliers. It follows that the interests of the EU as a whole cannot be realized in the markets of these countries and elsewhere in their areas of interest, while allowing other country's energy resource suppliers to profit in EU markets, which results in a major loss of business opportunities for EU companies. This applies particularly to the Russian gas concern JSC 'Gazprom', which provides a part of the necessary supply of natural gas for the EU. For example, in the EP session document 'European Parliament Resolution on the EU-Russia Summit in Nizhny Novgorod on 9-10 June' the EP has stressed that the main instrument of Russian foreign policy is power industry and that it is exactly power industry that continues to have the central and decisive role in the relations between Russia and the EU. In this document, the EP predicts that the dialogue between Russia and the EU on energy issues in the foreseeable future may become more exacerbated because in the field of energy the competition of the EU and Russia concerning common interest areas such as Central Asia and South Caucasus is becoming more exacerbated. In recognition of this, it is impossible to deny the claim that the strategic objectives of the EU for the use of RES by the year 2020, associated with energy supply, energy security and climate change issues attains another rational argument – it addresses the major geopolitical issues of the EU and creates new business opportunities in the EU. Here it is possible to affirm, that in such a way the contingent, but 'business' of the EU. The emphasis in this context is focused on maximizing the opportunities of its own national economy, so that the newly created assets (equipment, technology, technical supply, etc.), which will be required to achieve the strategic objectives for the use of RES in the EU by 2020, would be created in the EU itself as much as possible and would even find an opportunity to market them outside the EU. Consequently, so that it would be a contingent, but still the 'business' of the EU. By implementing this approach, new jobs and opportunities to invest not only in the power sector, but in all of the related areas of this process, are created. This can be explained by the fact that an investment in the power sector is only the final step in the whole process, through which the investments and expenses made, for example, in science, education, technologies, manufacturing and service sectors, which ensure the progress towards the realization of the strategic objective for the use of RES, are recovered. Considering the subject of the economic interests point of view (the limit for the raise of energy cost, with the increasing use of RES), it is a considerable opportunity to simultaneously improve indicators of economy, environment and society, contributing towards the further development of the economy (Adelle, et al., 2011 and the European Parliament, 2011).

2. The use on non-renewable energy resources in the perspective of low-carbon dioxide emissions economy

EU strategic power industry policy, the so-called '20-20-20' initiatives (or objectives) are included in 'Europe 2020: A Strategy for Smart, Sustainable and Inclusive Growth' (COM (2010) 2020 final), approved by the European Council in June 2010, and they are related to the priority of sustainable growth. Sustainable growth means building a resource efficient, sustainable and competitive economy (flagship initiative: 'Resource Efficient Europe'). With this approach, the EU is particularly planning to develop environmental technologies, to succeed in low carbon dioxide emissions and under limited resources condition, and promote employment, productivity and social cohesion (European Commission, 2010b).

The EU power industry policy orientation described above, which is focused on an integrated energy and climate change policy, where the objective is an economy that has a positive impact on the climate and is based on low carbon dioxide emission technologies and energy sources, in the foreseeable future does not exclude the use of any energy resource. Supporting the use of fossil fuels in the foreseeable future, rather than directly limiting (under the condition if the transfer to a low level carbon dioxide emissions economy occurs) a precondition is created for the promotion of a new industrial revolution (Figure 1), to promote the development of environmental technologies. It is important because environmental technology is like a potential for promoting growth, i.e., new and innovative environmental technologies can stimulate the growth of economy in various ways, while improving environmental indicators and conserving



Source: The Scottish Government, 2010

Figure 1. **Dimensions of a Low Carbon Strategy**

natural resources. Consequently, resources which can be used in other sectors of economy are freed, stimulating the economy as a whole. This in its turn helps to separate environmental pollution and the use of resources from economic growth, creating more opportunities for long-term economic development (Goossens and Meneghini, 2008).

The approach, which exists in the EU regarding questions about the use of fossil fuels in general, can be described by the phrase included in a publication by the EC 'Combating Climate Change: the EU Leads the Way' – 'While curbing the use of fossil fuels may mean we live differently in the future, it does not mean sacrificing our standard of living, now or in the future. Technology can make a major contribution to more efficient use of energy in our everyday lives, in industry, in transport and in sustainable development'. The development of energy technologies of the EU includes renewable energies such as wind, biofuels and solar, as well as sustainable coal and natural gas power plants, including carbon dioxide capture and storage, and fuel cells and hydrogen, advanced fission power and fusion. All this should be done in combination with better use of energy in conversion processes, in buildings, industry and transport. With this approach, the EU addresses the issue related to the renewable energy cost reduction, the promotions of effective energy use and ensuring the leading role of European companies in the field of low carbon dioxide emissions technologies (European Commission, 2007 and the European Commission, 2008).

The central role of an economy with low carbon dioxide emission levels (Figure 1) will play electricity. This nuance justifies yet more the reason why in the foreseeable future the EU power industry policy will be focused on increasing the use of RES in energy production, but at the same time also focusing on the development and future use of technologies based of fossil fuels. It should be stressed that it is not only related to the projected demand for electricity, but also the preparation of an energy infrastructure, to be able to integrate significant amounts of electricity generated from RES in a single European energy network (European Commission, 2011).

It is expected that from all of the energy resources, natural gas will be the one that will increase its use the most in the EU by 2020. That is, until the year 2020, an insignificant reduction in the use of coal and oil products by the EU is predicted, compensated by the increased use of natural gas. As a result, by the year 2020 natural gas could play the main role of energy resource in electricity production in the EU. As a clear proof of the adequacy for the natural gas consumption forecasts described above is the current trend in the use of natural gas in the EU, when the demand influenced by both the market forces and the preferences of member state policies is increasing rather rapidly. For example, from all of the newly installed electricity generation in the EU in the year 2010, the capacity of approximately 57 GW (gigawatts), just the use of natural gas equipment accounted for about 31 GW (The European Wind ..., 2011).

Conclusions

The EU policy in the field of RES can be divided into two periods: from the end of 1990's to the year 2008, when the promotion of RES use with indicative objectives in electric power supply and transport sector was in the focus of attention, and the second period starting from the year 2008, when the emphasis changed to defining legally binding objectives based on a comprehensive regulation, covering the use of RES in all key energy sectors.

In recent years, the use of RES in the EU is being recognize more and more as an area that cannot only address the issues related to security of energy supply and sustainable development, concerning the limitation of GHG emissions, but also providing new jobs and an incentive for the development of new technologies (employment factors).

EU power industry policy progress focused on an integrated energy and climate change policy, promotes ambitious objectives regarding the use of RES, but at the same time focusing on the development and use of non-renewable energy resources in the foreseeable future.

By supporting the use of non-renewable resources in the foreseeable future, preconditions are created for the promotion of a new industrial revolution to encourage the development of environmental technologies, which in its turn can be the potential for economical growth.

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POSSIBILITIES FOR RENEWABLE ENERGY PRODUCTION ON FARMS

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Abstract
An analysis of the consumption of energy resources in 1990 and 2010 revealed a significant change in the consumption pattern – the proportion of firewood rose. However, a draft strategy for the country's energy industry in 2030 envisages a very sharp increase in the consumption of renewable energy sources (RES). The present research identifies the possibilities for increasing the production of RES. It shows the possibilities for increasing the production of firewood and outlines the significant possibilities for increasing the production of RES in agriculture. It was ascertained that the achievement of targets to increase the output of RES by 30% in 2020 and by 70% in 2030 compared with 2010 was possible.
Key words: renewable energy sources (RES), firewood, biogas production on farms.

Introduction

Significant changes in the consumption of energy resources have occurred in Latvia since 1990. Their consumption decreased 40% over a twenty year period. The consumption pattern of energy resources also changed. It is a positive fact that the consumption of renewable energy sources (RES) significantly increased. The proportion of firewood consumption increased threefold, whereas the proportion of consumption of coal and oil products significantly decreased. A positive fact is that the import of electrical energy accounted for less than 20% of its total consumption in 2010 (44% in 1990). RES accounted for only 13.1% in the consumption pattern of primary energy sources in 1990, while presently their proportion has risen to a third.

The consumption pattern of primary energy sources in Latvia in 2010 was as follows: oil products – 32.2%, natural gas – 30.6%, firewood – 25.5%, electrical energy – 8.0%, coal – 2.2%, biogas – 0.3%, and others – 1.2%. It means that RES accounted for 32.9% of the total energy consumption. According to the draft "Energy Strategy 2030" (14 December 2011) developed by the Latvian Ministry of Economics, the proportion of RES in the energy consumption pattern has to reach 40% in 2020. Yet, in 2030, RES might account for half of the country's final energy consumption.

The draft "Energy Strategy 2030" envisages significant increases in the output of RES – 30% in 2020 and 70% in 2030 compared with 2010.

The mentioned national strategy envisages a very fast increase in the output of renewable energy sources. Researchers conduct comprehensive research on it, while at the same time discussions occur on whether such an increase in the output of renewable energy sources is possible and whether it is needed.

The research aim is to ascertain the possibilities for increasing the output of renewable energy sources in Latvia.

Research tasks:

1) to identify the possibilities for producing renewable energy sources;
2) to survey biogas facilities on farms;
3) to identify the possibilities for producing renewable energy sources of agricultural origin.

Materials and the methodology

The newest draft "Energy Strategy 2030" (14 December 2011) developed by the Latvian Ministry of Economics in cooperation with scientists was used to elaborate the paper. In the analysis of the consumption of primary energy sources, data of the Central Statistical Bureau for 2010 were used and compared with corresponding indicators for 1990.

Previous research findings of researchers were used for identifying the prospects for producing and exploiting renewable energy sources. To ascertain the possibilities for increasing the output of renewable energy sources of agricultural origin, data of a survey of farms and biogas facilities were used.

To obtain and process data, the following research methods were employed: the monographic method, synthesis, sociological surveying of farms, as well as the logical and constructive methods.

Results and discussion

Presently, the most significant RES in rural areas is forests, i.e. firewood, which accounted for a fourth in the energy consumption pattern in 2010. Forest lands occupy almost half of the area of Latvia, therefore, their role in producing RES will be increasing. According to studies, the growing stock of timber does not decline irrespective of intensive logging and exports of wooden products; it even increases and exceeds 630 mln m^3 (2010, V. Strīķis et al.).

According to calculations performed by L.Bite and K.Makovskis (2011), firewood accounts for almost 80% of RES in the consumption pattern of

Table 1

Characteristics of biogas facilities on farms in 2011

Regions	Number of biogas facilities	Energy capacity MW	Substrates (number of facilities)		
			manure	biomass of plants	other
Zemgale	12	11.8	12	12	-
Kurzeme	11	11.2	10	10	1
Riga	8	6.0	8	8	-
Vidzeme	8	10.0	6	6	2
Latgale	6	5.6	5	5	1
In Latvia	**45**	**44.6**	**41**	**41**	**4**

Source: data of the authors' survey

primary energy sources. By using findings of also other authors (M. Graudums, V. Lazdāns, 2010; A. Pelane, I. Ukenābele, 2008), these researchers found that by-products such as tree branches, stumps, etc. were insufficiently exploited. Yet, A.Broņka and A. Zvirbule-Bērziņa (2011) developed principles for local governments regarding exploiting firewood resources, i.e. they presented the opportunities for increasing thermal efficiency by modernising boiler houses powered by firewood. According to the studies, the exploitation of firewood, which is the most popular renewable energy source, may be increased by 16% in 2020 and 30% in 2030 compared with 2010. Therefore, the proportion of firewood in the energy consumption pattern will reach 27.7% in 2020 and 30.3% in 2030. Thus, that part of the draft national energy strategy, developed by the Ministry of Economics, which deals with increasing the consumption of firewood might be achieved. Regardless of the possibilities identified for increases in the consumption of firewood as well as in its exploitation efficiency, the proportion of firewood in the RES consumption pattern will decrease from 77.8 (2010) to 69.9 (2020) and 60.5 (2030) percent, as other RES in the energy consumption pattern will increase much faster (2011, Enerģijas...).

According to the energy strategy forecasts for 2020 and 2030, the consumption of biogas and liquid biofuels (bioethanol and biodiesel fuel) has to sharply increase. The consumption of biogas and liquid biofuels totalled 0.56 PJ or 0.9% of the total consumption of RES in 2010; in 2020 and 2030, it would already reach 1253 PJ or 14.7% and 24.17 PJ or 21.8%, respectively (2011, Enerģijas...).

According to the energy strategy, it is necessary to rapidly develop a new industry – energy production – in rural areas.

The previous analyses and studies indicate that the future development of the energy sector, to a great extent, depends on agriculture. It is a positive fact that farms are responsive and started producing RES.

A survey of farms conducted at the end of 2011 showed that 45 biogas facilities operated or were built. Of the biogas facilities, 12 with a capacity of 11.8 MW were located in Zemgale planning region, 11 with a capacity of 11.2 MW were situated in Kurzeme planning region, 8 with a capacity of 10 MW – in Vidzeme planning region, 8 with a capacity of 6 MW – in Riga planning region, and 6 with a capacity of 5.6 MW – in Latgale planning region. One can see that the biogas facilities are located across the entire Latvia. Several such facilities are at the stage of designing or construction (Table 1).

Manure, biomass of plants, and production by-products are used as substrates in biogas production. In biogas production, 41 farms used manure, 41 farms processed green biomass of plants, and 4 farms – by-products from agricultural production. By-products from agricultural production or food trade were partially used or it was possible to use them at other biogas facilities as well.

Of the 45 biogas facilities surveyed, 23 started producing electrical energy. These facilities started using thermal energy as a by-product as well. A biogas facility project was completed on nine farms, while such a project was at the stage of implementation on 38 farms.

The number of biogas facilities broken down by installed electrical capacity was as follows: 22 with a capacity of less than 1 MW, 12 with a capacity of 1 MW, and 11 with a capacity within 1-2 MW. The total installed electrical capacity of biogas facilities built or being under construction will reach almost 45 MW or on average 1 MW per farm.

Various amounts of funding were approved and paid out for constructing biogas facilities in 2011 (Table 2).

The distribution of biogas facilities by amount of electrical energy sold within the renewable purchase obligation a year (MWh) was as follows: 15 facilities sold less than 5 000, 18 – within 5 001 – 10 000, and 11 – more than 10 000.

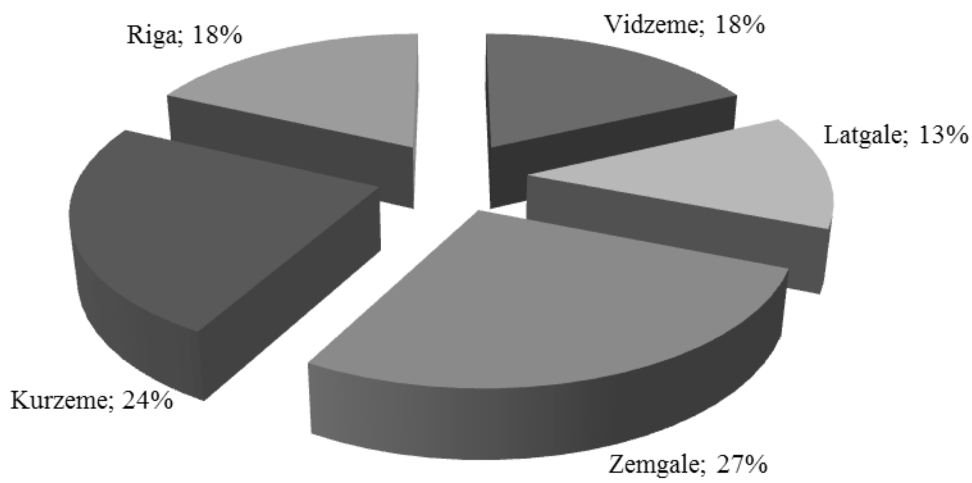
The survey showed that the farms engaged in producing biological energy sources were located

Table 2

Number of biogas facilities by amount of public funding for construction in 2011, mln LVL

Groups of biogas facilities by amount of funding, mln LVL	Number of biogas facilities by amount	
	approved	paid out
less than 0.5	6	12
0.6-1	23	5
more than 1	11	6

Source: data of the authors' survey



Source: data of the authors' survey

Figure1. **Percentage distribution of the farms engaged in producing renewable energy sources by region in Latvia in 2011**

across the entire Latvia, although a slightly leading position belonged to Zemgale region (Fig.1).

To rapidly increase the output of biogas and liquid biofuels, it is necessary, first, to find out the potential of producing and exploiting agricultural energy crops and the economic conditions; second, to determine the development possibilities for the output and exploitation of manure and other agricultural and food production wastes (by-products) for biogas production and also to set the economic conditions for developing intensive livestock farming. Third, institutional mechanisms, funds, and qualified human resources are needed for producing RES of agricultural origin.

Several researchers such as A.Kalniņš, A.Adamovičs, Z.Gaile, V.Dubrovskis as well as scientists from Riga Technical University (RTU) have published their findings on production and exploitation of RES. These researches are continued and extended; the number of researches performed by scientists of Latvia University of Agriculture and RTU over the recent years proves it.

According to the survey of farms as well as studies carried out by the Latvian Advisory and Training Centre in 2011 and its publication "Demonstrations in Crop and Livestock Farming 2011", approximately 1000 ha of agricultural land are needed for producing substrates for a biogas facility with an electrical capacity of 1 MW. Such an area is needed for growing feed for livestock, of which a by-product – manure used in biogas production – is produced as well as for growing green biomass.

At least an area of 0.5 mln hectares of agricultural land may be exploited for growing green biomass in Latvia. Such an area, according to land use data of various institutions, is not exploited or is used extensively (Zemes...2011). Such an area may provide resources for biogas facilities with a total electrical capacity of approximately 500 MW. It means one biogas facility may be built in every rural parish.

According to studies on the conditions of producing and exploiting agricultural energy crops, large-scale intensive agricultural production has to be promoted and financial investments and entrepreneurial farmers have to be attracted. Experience shows that presently, the best conditions are observed in Zemgale region (2010, J. Klāviņa et al.).

Zemgale is the least wooded region compared with the other regions. However, it has the most fertile soils. The average fertility of agricultural land is 38 points, while in Zemgale it is 56 points. The highest proportion of arable land is in Zemgale compared with the other regions of Latvia. The total area of arable land in Latvia was 1190 thousand hectares in 2010, of which 291 thousand hectares or 24% was in Zemgale. Zemgale region is an area of intensive agriculture. Around half of Latvia's agricultural incomes are gained in Zemgale, although only one fourth of arable land is located in this region. It means that agricultural intensity in this region is twice as high compared with the other regions (2010, FADN data).

An analysis of FADN data showed that the highest proportion of economically largest farms, compared with the other regions of Latvia, was observed in Zemgale. An average area of agricultural land per farm was also greater in Zemgale. Besides, farms having a greater area of agricultural land had a greater total standard gross margin. Yields of crops were also higher in this region. It indicates that intensive agricultural production is specific to Zemgale. Yet, yields are equal if the economically largest farms are compared among various regions. It means that the economically largest farms of various regions having appropriate resources and modern agricultural technologies perform equally. The yields of energy crops (sunflower, maize etc.) in Zemgale in 2010 were 40% higher than in 2005. In general, yields of livestock feed crops tend to increase, which indicates an increase in the level of agricultural technologies. These trends also point at large possibilities for growing agricultural energy crops at optimal costs.

The researches conducted showed that large investments as well as a large area of agricultural land and intensive production, which was specific to modern large-size farms, were required to engage in producing RES for biogas production. At the same time, studies of foreign literatures and experiences of farmers showed that it was possible to engage in the production of RES by means of agricultural cooperation, i.e. by cooperating with medium-size farms or by building biogas facilities of small capacity.

The analysis of survey data for farms and the findings of scientists showed that the output of biogas and other biofuels envisaged in the strategy, according to the Ministry's of Economics forecast, might be reached.

Conclusions and proposals

It is necessary to develop energy production on farms in order to meet the sharply increasing demand for renewable energy sources (RES); a survey of farms shows that 45 biogas facilities operated or were built on farms in 2011.

Biogas facilities are located in all the regions of Latvia. Presently, the best possibilities for their development are in Zemgale which is a developing region of intensive agriculture. Yet, in the future, with increase in intensive agricultural production in the other regions, the output of renewable energy sources will increase there as well.

An analysis of the performance of biogas facilities of farms and the research findings as well as the calculation show that it is possible to meet the demand for RES produced in Latvia as envisaged in the Energy Strategy if 0.5 million ha of agricultural land are engaged in the production of RES.

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DEVELOPMENT OF INSTITUTIONAL ENVIRONMENT TO PROMOTE THE USAGE OF RENEWABLE ENERGY RESOURCES IN LATVIA

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Abstract
The pattern of energy production and consumption changed rapidly during the last 15 years. The aim of the paper is to characterise the development of institutional environment in RES promotion within the last 15 years. The analysis reveals that attention to RES promotion in the nation was paid only before the accession to the EU. During the institutional environment creation and harmonizing with the EU institutional and legal system after the accession to the EU, the RES institutional environment became even more unstable and predictable. Formal targets are stated in planning documents, but the realisation of support schemes for RES changes each year since 2007. Thus, the increase of support amount does not result in an increase of RES proportion in the energy sector. The results of RES promotion will not be seen in the nearest future immediately, it takes time for Latvia's producers and farms to adapt and optimise technologies for active electricity and heat production from RES. The most stable support available in Latvia is accessible through EU funds.
Keywords: renewable resources, institutional continuity, EU support.

Introduction

In economic theory, the concept of institutions is used most often in new institutional economics (Шаститко А.Е., 2002). The main idea of this concept is that during economic growth and rapid structural changes, the role of institutions increases. In many studies of international and national level on economic environment, key aspects are institutional performance, stability and their predictability. According to the terminology in new institutional economics, institutional environment is basic political, social and legal rules, which create a base for production, exchange and distribution. Institutional continuity and predictability of institutional changes are also very important. Researchers also draw attention to the existence of historically formed political and economic institutions and their resistance to the changes (Acemoglu and Robinson, 2006). In context of institutional economy, it should be noted that:

- Weak institutional regulation and its non-compliance with a legal system prohibits firms better performance;
- From the point of view of macroeconomic stability and political and legal system predictability, private sector is a greater winner than public sector when transparencies of institutional environment are at a low level.

The mentioned aspects often give background for unfair behaviour between competing firms. Such situations arise due to concentration of market (for example, monopoly or oligopoly in energy sector), a high proportion of state property and state controlled firms, as well as due to slow production factor mobility (land, estate).

Researcher also stated that resources have only a partial impact on growth processes, but they create initial conditions for emerging of institutions (Acemoglu et al., 2002). Fr. Fukujama (2006) believes that growth initiators are institutions which in many cases are exogenous regarding material resources used by society.

Despite strong political formal policy regarding renewable resource (RES) promotion in Latvia, there are several barriers. One of the most mentioned reasons is the relatively high cost of introducing RES technology. The second most often mentioned barrier is the institutional environment in RES promotion.

The aim of the paper is to characterise the development of institutional environment in RES promotion within the last 15 years. The tasks of the paper: 1) to discuss theoretical premises on the role of institutional environment; 2) to describe the formation of institutional environment at national level; 3) to summarise the impact of EU working policy on RES promotion in Latvia.

Materials and Methods

The theoretical part of the paper is based on the interpretation of international researches (monographic method). The paper also contains materials from researches and publications in the renewable energy field which are produced in ESF researches "Attraction of Human Resources to Renewable Energy Resources", as well as statistical data. In the paper, the graphical method was also used.

Results and Discussions

Institutional framework

The most anticipated definition of institutions is based on D. North's formulation – institutions are rules in society, or more formally, constraints created by people, which influence cooperation (North D., 2003).

A similar definition is given by Nobel prise winner in economy E. Ostrom – institutions can be defined as norms, used to find out who has power to decide in every situation, which activities are allowed and which are not, what type of procedures will be prosecuted and what kind of benefits will individuals get (Nystrom K., 2008).

According to the neo-institutional economy paradigm, the autocracy, contracts, cooperation or even markets are solely organizational solutions to guarantee different types of responsibilities and rights. The very existence of the governance structures and their performance reveals how institutions work and influence economic activities. Thus, institutions create some sort of environment in which all types of human activities are located, including economic ones.

Main formal elements of institutions are rules. They create relationships between firms, thus reducing risks and simultaneously show potential profits or costs. However, the formation process of institutions is always based on asymmetry between involved parties. Asymmetries manifest as:

- unequal distribution of power;
- unequal distribution of wealth and resources;
- advantages in access to information flow;
- differences in priorities and individual norms.

Regarding RES promotion, the asymmetry reveals itself in special support. According to the EU – „"support scheme" means any instrument, scheme or mechanism applied by a Member State or a group of Member States that promotes the use of energy from renewable sources by reducing the cost of that energy, increasing the price at which it can be sold, or increasing, by means of a renewable energy obligation or otherwise, the volume of such energy purchased. This includes, but is not restricted to, investment aid, tax exemptions or reductions, tax refunds, renewable energy obligation support schemes including those using green certificates, and direct price support schemes including feed-in tariffs and premium payments" (Direktīva 2009/28/EK). The author of this paper stated that regardless of this special support created by the EU, in Latvia the market of energy produced from RES suffers serious institutional problems, namely:

- asymmetry of information between potential producers and consumers;
- asymmetry of power between Latvenergo (monopoly) and local small scale producers in electricity generation;
- legal system in energy production and energy market 'quasi' compliance with the logic of energy policy at national level;
- capacity of state and local institutions in decision making about RES promotion is restricted by the lack of knowledge due to low investments in researches on economic, social and technological benefits of RES.

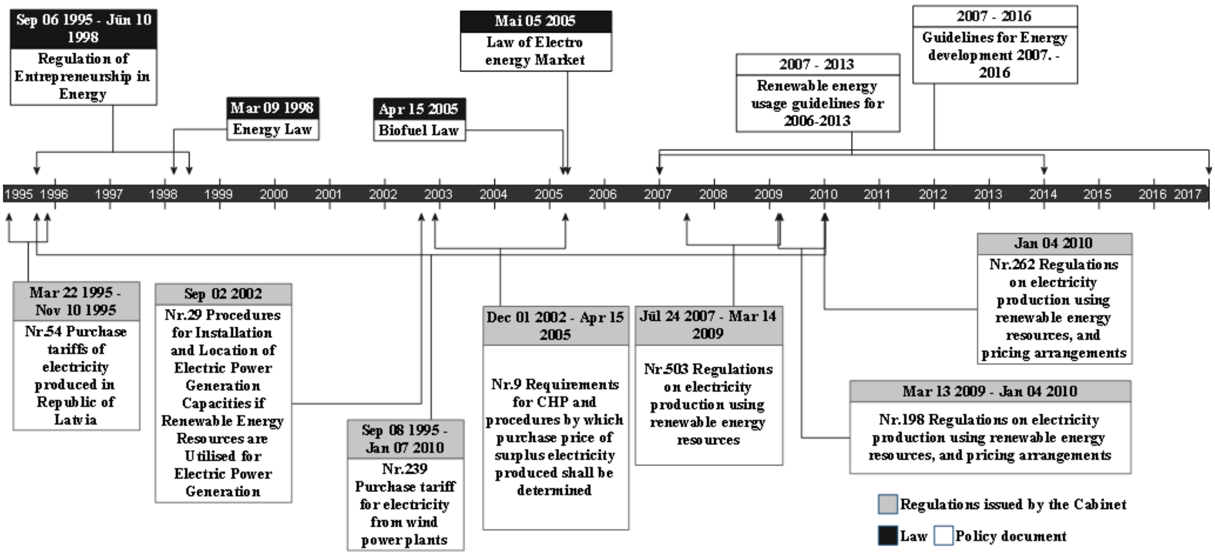
The first researches on RES usage in Latvia were done by energy sector specialists. Economic aspects of RES were not published by public research institutes till 2007. Increased attention toward RES promotion can be explained by at least two factors. First – the accession to the EU (2004) was possible also by a government promise to increase the proportion of RES and agreement with the common EU policy on RES promotion (regardless of the level of this proportion). Second – the national economy greatly improved till 2008. It should be noted that the hydro power plants had a favourable support system already since 1992 regardless of those events.

A national government determines not only the support system type and continuity, but also defines a normative system and procedures to follow. Traditionally the welfare economics approach does not analyse such outside market interventions (such as direct payments, taxies for fossil energy users etc.) because politics and economy are considered as two totally unrelated parts of human activities (Patrick M., 2008).

National level

The pattern of energy production and consumption changed rapidly during the last 15 years. Only five years after regaining indecency in 1990 through the process learning by doing, the first law regarding RES usage in energy sector come into force „Regulation of Entrepreneurship in Energy" (1995). Through the existing regulation at that time we can state that only two types of RES were acknowledged as considerable – hydro power plants (in Regulation No. 54) and wind (in Regulation No.239). A support amount for small and medium HPP (<5MW) was impressive – twice the average purchase tariff. This caused a building boom of HPP regardless of environmental problems which at that time had no regulation in the legal system. The need to reorganize the whole energy sector according to free market principles forced to issue the "Energy Law" in 1998. This law partially solved the problem of small HPP and their rather tiny impact in energy production (most of them were built solely for easy profit), defining the procedures and principles to support practically all RES types, including even geothermal (despite that no sufficient research data were available). The parliament, by issuing the "Energy Law", also delivered all power in RES support regulation to the Cabinet of Ministers, thus ending four year struggle for real legislative power in this field. All these events were accompanied by corruption scandals in high bureaucracy levels and uncertainty about energy policy development in the future.

From 1998 till 2005, the all RES support system was largely maintained and based on the Regulation of the Cabinet. Frequent changes in the "Energy law" regarding RES during this period and unpredictability in the Regulation (changed each year) prevented potential RES producers to invest. The Regulation of the Cabinet each year stated quotas for installation



Source: Author's summarised data

Figure 1. **History of basic regulations and laws regarding renewable resources usage in the energy sector in Latvia during the last 15 years**

of new electricity generation power and the purchase amount of electricity from these new power plants. Since the procedures and amount and price of quotas changed each year, energy producers appeared offering different purchase prices for the same type of resource. So, in 2004 there existed even four types of pricing, most often in hydro power usage. It should be noted that RES usage was promoted only in electricity. That period also can be characterised as politically unstable, the average ruling time of national government was one year.

In 2005 after the accession to the EU, the RES institutional environment become even more unstable. The "Law of Electricity Market" (2005) came into force and direction from the quota system was switched to the compulsory purchase system. In this year the "Biofuel Law" was also issued. At the moment, the "Law of Electric Energy Market" is a basic normative act at national level and regulations in RES support are issued largely based on this law. Two years after the acceptation of the "Law of Electricity Market", no institutional procedures and rules were created to specify the support. However, even after 2007, the real aim of these regulations and policies was not clear. EU political pressure to support RES usage in more extensive way finally forced the Cabinet, after three years, to define targets and instruments for RES in Latvia (see Fig. 1).

In 2006, the Ministry of Economics worked out the "Guidelines for Energy Development 2007-2013" and the Ministry of Environment worked out the "Renewable Energy Guidelines for 2006-2013". Mutual compliance of both guidelines is under question. In 2011, the new Energy policy is under revise and in 2012 we wait for a new integrated Energy policy document (LR EM, 2012, homepage).

Both planning documents defined targets and tasks for promoting RES usage increase, however, the main target is to achieve stable balance between energy demand and consumption during 2007-2016. In these institutional framework documents, basic tasks and potential instruments has been drawn, for example, to increase energy usage efficiency, to secure supply from local electric energy plants which use local and renewable resource with high electivity level cogeneration. The rest of energy demand should be covered with other fossil resources, thus reducing high dependence on natural gas. So, at national level, the main tasks are security and stability of energy supply as well as to cope with energy demand (Guidelines for Energy Development 2007-2013).

According to "Renewable Energy Guidelines for 2006-2013", the Cabinet also stated that the highest potential is in biomass and hydro resources, less attention is paid to wind energy usage and biogas production. The "Law of Electric Energy Market' (2005) and the "Biofuel Law" (2005) stated the targets of increase of proportion of RES in final consumption, however, the one unified strategy to achieve these target is absent (Dzene I., Marika R., 2008). Analysis of regulations issued after 2007 till 2011 shows that the Cabinet has not decided on a clear and predictable promotion system for increase of RES in final consumption. Based on these Guidelines, the "Biogas Production and Usage Development Program 2007-2011" was issued in 2006.

Regulation No.503 (2007) is practically the first national practical document because it defines the procedures and rules to get a compulsory purchase quote for renewable energy producers (see Fig.1). Despite many un-clarities and non-compliance with other regulations (till 2009), the first real stimulus

Table 1

Compulsory purchase of electricity according to the Cabinet Regulation No. 262. „Regulations on Electricity Production Using Renewable Energy Resources and Pricing Arrangements" in 2011

Type of energy	Amount offered by public buyer, MWh	% of total	MWh	% of total	Compulsory purchase amount, MWh	% of total
Hydro (<5 MW)	131 106	9.8	81 810.0	7.8	49 296.0	16.8
	100%	-	62.4	-	37.6	-
Wind (<0,25 MW)	17 878	1.3	13 163,5	1.3	4 714.5	1.6
	100%	-	73.6	-	26.4	-
Wind (>0,25 MW)	337 697	25.2	294 151.3	28.1	43 545.7	14.8
	100%		87.1		12.9	
Biogas	525 085	39.2	471 102.7	45.0	53 982.7	18.4
	100%	-	89.7	-	10.3	-
Biomass and fossil	329 089	24.5	187 149.7	17.9	141 939.3	48.4
	100%	-	56.9	-	43.1	-
Solar	662	0.0	580.0	0.1	82.0	0,0
	100%	-	87.6	-	12.4	-
Total	1 340 855	100	1 047 690.1	100	293 565.3	100

Source: LR ME homepage (2011)

for biogas and biomass usage promotion was created. Simultaneously regulations to support increase in biomass and biogas usage in cogeneration was issued. The inability of national government to decide on a more active promotion system has been shown by issuing Regulation No. 503. However, Regulation No. 198 "Regulations on Electricity Production Using Renewable Energy Resources and Pricing Arrangements" (2009) appeared thanks to increased knowledge of potential benefits of RES. This regulation cancelled connection between a purchase price of electricity from renewable energy resources and a natural gas market price. With this regulation, the RES system at national level has been clearly directed towards mixed schemes regarding the compulsory purchase and quota systems. In May of 2011, such mixed support has been cancelled for unknown reasons (Regulation No.262). Till the summer of 2011, it was possible to participate in a support scheme which contained:

- Rights to sell electricity in the compulsory purchase system (Regulation No.262, 2010);
- Right to get guaranteed support for electricity power installed in an electricity station (Regulation No. 262, 2010);
- Right to get guaranteed support for electricity power installed in a cogeneration station (Regulation No. 221, 2009);
- Rights to sell electric energy produced in cogeneration in the compulsory purchase system (regardless of resources used) (Regulation No.221, 2009);
- Participation in the quota system for biofuel (Regulation No. 280, 2008).

In addition to the mentioned mix of quota and purchase systems, other institutional instruments exist to promote and stimulate fossil resource change with renewable ones. The Ministry of Agriculture manages instruments of EU funds – supports biomass growing and biogas projects; the Ministry of Economics - electricity production from biomass and biogas, biofuel production (since 2007), but the Ministry of Environmental Protection and Regional Development – the Climate Control Instrument (since 2008). No instruments exist to promote renewable resources usage in heat production.

The data publicly available in the homepage of the Ministry of Economics (since the autumn of 2009) allow us to summarise practical results of the mentioned promotion schemes during 2009-2011 (see Table 1). Wind power stations (WPS) with a power of over 0.25 MW are the most actively newly registered (87.1% of all quota) plants, the second are biogas plants – 89.7% of all available quotas. A vertical analysis by comparing differences between resources reveals that the public seller (JSC Latvenergo) keeps little value sun energy and WPS with a power of less than 0.25 MW (available total amount of quota is around 1%). Biogas (39.2%) and WPS with a P>0.25 MW (25.2%) are considered as a potentially better solution.

Each year since 2007, JSC Latvenergo (a natural state-owned monopoly in electricity transmission and distribution in Latvia) calculates a needed amount from RES (with the main aim – to cover shortages in electricity and decrease the import proportion). The principles of quote creation are based on Latvia's RES targets in 2020. However, the proportion of RES type,

Table 2

KPFI projects connected with RES promotion and their budgets

Title of project	Budget of the project (LVL)	Year of announcement
1. Technology development in greenhouse emission reduction	1 741 560	2010
2. Transition from fossil energy to renewable energy resources	8 082 346	2010
3. Usage of renewable resources in transport	3 522 621	2010
4. Usage of renewable resources in households (I part)	4 432 721	2011
5. Usage of renewable resources in households (II part)	7 218 785	2011
6. Usage of renewable resources in reducing GHG emissions	27 716 876	2011
7. Development of technologies which reduce GHG emissions and realization of pilot projects	2 793 646	2012

Source: MEPRD homepage, 2011

(wind, solar, biogas etc.) that has been stated each year by Latvenergo, is not publicly available. That caused the lack of quota for potential wind energy producers in March of 2009 because the available amount of quota has been distributed within three weeks. It should be also noted that many producers got the quota, having the electricity generation powers only on the paper, but the consumers already pay for that an increased electric energy tariff in which the RES proportion is also included (Public Utilities Commission home page, 2011).

Relatively newer state support is the „Climate Change Mitigation Programme for 2005-2010" (VARAM homepage, 2012). The Programme is based on the Kyoto Protocol to the Convention. Latvia signed the Protocol in 1998, and Saeima ratified it in 2002. The Programme is Latvia's state budget programme with the aim to mitigate climate change and to promote reduction of greenhouse emissions in Latvia. The primary goal of this programme – to ensure that starting with 2008, the total amount of GHG emissions does not exceed 92% of 1990 level. In this programme, there are also supported projects which involve using renewable energy resources. Real activities in this programme started only in 2008 when first agreements with partners were signed. However, a full report about projects and their results for the period 2008-2011 is not available yet (Report of Climate Mitigation Instrument in 2008, 2009). The latest available data are shown in Table 2.

The Program was not renewed after 2010, since it was clear that the Kyoto Protocol will be realized. The Ministry of Environmental Protection and Regional Development continues to work based on the accepted „Strategy for the Realisation the JI Projects under the UNFCCC Kyoto Protocol for the Time Period from 2002 to 2012". The total sum spend during this program so far is LVL 55 508 555, the most important project „Usage of Renewable Resources in Reducing GHG Emissions" was launched in 2011 with LVL 27 million.

Summarising the available data on support schemes on national level, the author has to agree with researchers' conclusion that they are fragmented and rather formal, since they have not essentially stimulated increase of renewable energy resources proportion in final consumption (E&IC, 2009). The legislation and support procedures has been changed very essentially within the last three years and even in the beginning of 2012 the policy is not clear about energy sector development and the role of renewable resources in it. This does not create a positive stimulus for potential investors in RES.

Impact of EU support

The EU working policy and legislation directed towards increase of electricity generation from RES and fossil fuel change to biofuel. The great push for doing that is the growing energy import dependency in all EU member states (EU Energy in Figures, 2010). The total amount of received subsidies during the last four years can be seen in Table 3.

Several measures are available for RES promotion:

- "Aid for Energy Crops" is a direct payment for areas in which energy crops are grown, which are utilised for the manufacture of energy products (2007-2010);
- Rural Development 3. axis sub-programme offers measurement „Energy Production from Agricultural and Forestry Biomass";
- "Production of Energy Resources from Agricultural and Forestry Products"

The aid for energy crops stopped in 2010, since this measure exceeded a limit of 2 million ha of agricultural areas in the EU. Latvia's farmers started to receive this payment from 2008 till 2010. An analysis of direct payments for growing energy crops shows that initially an average payment for it was lower, but later the number of farms stabilized. A regional analysis shows that most of such farms were located in Zemgale and Vidzeme. The total amount received in this measurement is LVL 1.88 million.

Table 3

EU funds in renewable resources promotion in Latvia and State subsidies

Measure	Measures	2007	2008	2009	2010
Energy production from agricultural and forestry biomass	LVL	x	x	4 788 177	5 883 317
	Number of farms	x	x	9	14
Production of energy resources from agricultural and forestry products	LVL	66 116	467 451	879 555	427 604
	Number of farms	4	10	15	7
Aid for energy crops	LVL	x	801 675	542 353	538 250
	Number of farms	x	430	168	170
State subsidies – annual biofuel support	LVL	4 938 179	3 946 161	6 872 771	4 310 482
	Number of firms	4	7	8	8

Source: author's made summary based on Rural Support Service data (2011)

Producers of energy resources from agricultural and forestry biomass received additional subsidies during the period 2007-2010 – in total LVL 1.84 million. However, the number of farms is rather small. We may conclude that this measure is received by a very short range of farms.

The biggest financial support in the EU Rural Development Fund is allocated to "Energy Production from Agricultural and Forestry Biomass" with a total amount of LVL 10.6 million. This support started only in 2009, but the number of farms is constantly increasing.

The highest support thanks to EU directives is received by private companies which produce biofuel. Within the period 2007-2010, firms received a special subsidy of LVL 20 million from the state budget. However, the increase of biofuel proportion in Latvia is not observed. So, in total, all firms and farms involved in biofuel, biomass, and biogas production received 34.3 million. The biggest part of this support is received in the last two years with many energy power installations in process.

There exist indirect supports since 2005 with issuing the "Biofuel Law" (2005) for biofuel with a lower excise duty and a compulsory proportion of biofuel in fossil fuel in 4.5-5% of final annual consumption. So formally Latvia has fulfilled institutional requirements regarding support for RES.

Conclusions

The pattern of energy production and consumption changed rapidly during last 15 years. Latvia historically has a relatively high proportion of RES in final electricity consumption.

From 1998 till 2005, practically the RES support system was largely created by several regulations of the Cabinet. However, increased attention to RES promotion at national level was paid only before the accession to the EU. During the institutional environment creation and harmonizing with the EU institutional and legal system after the accession to the EU RES, the institutional environment become even more unstable and predictable. Formal targets has been stated in planning documents, but the existing support schemes in Cabinet regulations for RES changed each year. The most basic rules of RES promotion are formed by regulations of the Cabinet (elaborated by the Ministry of Economics) since 1995.

Summarising the available data on support schemes on national level, the author has to agree that it is fragmented and rather formal, since they have not essentially stimulated the increase of renewable energy resources proportion in final consumption. The total amount of financial support through this support schemes is around 89 million during the period 2007-2011. No data are available on the effectiveness of compulsory purchase of electricity. Here, the role of the natural monopoly in RES promotion in Latvia has to be analysed more deeply.

The results of RES promotion will be not be seen in the nearest future immediately because it should take time for Latvia's producers and farms to adapt and optimise technologies for active electricity and heat production from RES in the exiting institutional environment. These farms and firms started to receive the real financial support only since 2008.

The most stable support available is accessible through EU funds in Latvia. RES support of the EU does not change so fast as that of Latvia.

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GLOBAL AND LOCAL CHALLENGES IN THE CULTIVATION OF FOOD AND ENERGY CROPS

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Abstract
Energy and food production recourses have never been considered to be competitive elements in Latvia to date, however, active public and political discussion is within the context of globalization. With the participation in international agreements, the production of the "green energy" and limitation of green house gases has substantially affected the production of farms in Latvia. The present article examines the development of international discussion, as well as different scenarios of land exploitation alternatives are analyzed both by the amount of produced energy and profitability per ha^{-1}. The described results in the article show that utilization of cattle-breeding manure is less effective by output amount per identical amount of agricultural land area. Comparing the profitability of alternatives – food (winter wheat) or energy (electricity from maize), energy production is more profitable.
Key words: energy crops, biogas production, food – energy dilemma, opportunity cost.

Introduction

Traditionally to obtain heat, firewood (woods cover 50% of the territory) or natural gas (imported resource from Russia) were utilized, electrical energy was obtained mostly from the biggest hydroelectric power stations or imported (Russia, Lithuania, Estonia); in the fuel market, complete monopoly dominated. In the food production in Latvia, crop overproduction is reached. This raw material is partly exported (basically as a primary resource), and we can supply ourselves with dairy products although the export of goods and imports exist, while worse indicators are observed in meat supply, and there is a very high import proportion. At the same time, there are large areas of unused agricultural land in Latvia, indicating the possibility to expand the production of agricultural produce. Though, the supply of food in the world is not as optimistic. The number of inhabitants has reached 7 billion; moist tropical forests are being cut more and more to lay out new areas for food supply as well as to construct infrastructure, moreover, these areas are used to obtain energy, including cultivating energy crops which are used not only in the provision of necessary food energy for humans, but also these crops are used as raw materials to produce electrical energy, thermal energy or transport energy. In this context, the competition for land productive area that can be used to provide food and energy resources develops. There is a certain coherence in the theory of economics that with the growth of the number of inhabitants, the consumption of resources grows; in addition, the more developed country is, the bigger is its consumption of resources. If at the moment in the economy of the developed countries such as the USA, the EU, Japan certain exhaustion of development potential is being observed, then in such developing countries as China, India, on the contrary, explicit tendencies of economic increase is being observed, in addition, it must be considered that these are countries with a great number of inhabitants.

These processes have defined the topicality of this article; **the aim** of the article is to analyze the mutual competition for land in the cultivation of food and energy crops. To reach the aim, the following **tasks** have been advanced: 1) to emphasize the most substantial international documents that identify the necessity to increase the amount of food and renewable energy resources; 2) to analyze individual international studies in explaining the food and energy dilemma; 3) to analyze comparisons of land exploitation alternatives by produced energy (kWh – total economic energy and Kcal – food energy) and profitability per ha^{-1}.

Materials and Methods

The theoretical basis of the article is grounded on the study of international documents and materials of international research projects. The former researches and publications on renewable energy by the authors are used in this article, including the data obtained within the ESF project "Attraction of Human Resources to the Research of the Renewable Energy Sources", as well as data bases of statistical indicators, and Internet resources. The process of production of electric power in a cogeneration station is examined as a kind of renewable energy within the research where corn silage is used as a basic substratum, which is the most popular in Europe now and in Latvia it is the most popular and most cultivated energy crop to produce bio energy in cogeneration stations. In Latvia, the winter wheat is chosen as the basic raw material for foodstuffs; this cultivated plant can supply a big part of the consumed amount of flour in the country and a part of the produce is exported. In the mathematical calculations, the price lists of 2011 of Ltd. "Latagra", Ltd. "Latfert" and Genuine Seeds of Latvia have been used, but for calculations of service expenses, the information on price levels for 2010 from the Latvian Agricultural Advisory and Training Centre have been used. The technological scheme of crop cultivation is taken from a practicing farm in Latvia. The monographic, inductive and deductive methods are used in the study, as well as the graphic method. The calculations of expenses of crop cultivation and production of basic products are made using the method of expense calculation modeling.

With the concept of energy crops, the authors have identified all those cultivated plants that are grown taking into account appropriate agrotechnical demands and that are used to obtain energy (thermal energy, electric energy and/or fuel).

Results and Discussion

Global challenge

During the last century's 80's, a new tendency appeared when the consumption of resources exceeded the capacity of its reproduction. By now the scientists have calculated that the mankind consumes resources by 30% more than it can generate within a year. The industrial period started the era of utilization of fossil resources. If till then mostly renewable resources were used, then by now these are mostly natural gas and oil which have become the main energy resources outpacing the amount of coal utilization. To ensure energy of different kinds, primary energy resources are essential – deliberate reserves of fuel and energy resources that can be applied directly or to obtain energy. Wherewith the questions concerning the obtaining of energy resources and their utilization for the needs of society are the central ones on a local, regional and global scale; and taking into account that the International Energy Agency anticipates that within the foreseeable future the demand for energy will only increase, these questions indisputably become more topical and at the same time more imminent (International Energy Agency, 2011). It is not planned in the immediate future to cultivate new deposits of fossil energy resources in large amounts, rather the amounts will decrease, of course, if new still unknown deposits are discovered. Moreover, as experience shows the cultivation of new fossil deposits becomes more expensive, they are found in deeper layers, in areas that are difficult to reach, which raises the price. 300 million years were needed to create the energy of mineral resources, but only in the next couple of years it is possible to expend the biggest part of energy resources up to the minimum. According to the predictions of British Petroleum, the oil may suffice for 40 years yet, afterwards to obtain the last of its resources, more energy will be needed than it is worth; but natural gas resources may suffice for 60 years yet. If the coal is to be used to compensate these resources then the resources of coal may suffice for 125 years yet. Such a situation will remain even if we calculate that during a year, the worldwide demand for energy increases only by 1% for oil and 1.5 % for natural gas, but it is a slower increase than currently.

If electric energy, thermal energy and energy necessary for transport are secondary to ensure human's basic needs, then food is a primary source of energy, the society cannot exist without it. In particular the issues on food supply in the international area became more acute in the last century's 90s. Searching for a solution in Italy in 1996 during the UNO summit, the so called Rome declaration was established on World Food Security. It foresees that everyone has rights for safe and rich in nutrients food that is adequate in amount and ensures the basic right for a human not to suffer starvation. During this resolution, the countries showed their political will to exterminate starvation in all countries of the world, foreseeing to reduce the number of people who daily receive insufficient nourishment till 2015 as well. (Rome Declaration on World Food Security, 1996) The number of people who suffered starvation in 2010 reached 925 million, mostly in developing countries. 26% of children till the age of 5 worldwide have insufficient weight because of insufficient nourishment. The EU in 2010 established a special program "EU Policy Framework to Assist Developing Countries in Addressing Food Security Challenge" that was created with a prediction that till 2015 the total demand for food will increase by 70% with the growth of population till 9 billion. (EU Policy Framework to Assist Developing Countries in Addressing Food Security Challenge, 2010) Further the food will have to be produced using smaller areas of agricultural land, water and also less pesticides, sustainable agro ecological production methods will have to be applied. The EU parliament, within the framework of the program for world food security, emphasizes the importance of political stability to improve food supply considering that world food crises is not only a previously unprecedented progressive human problem, but also the threat for peace and security worldwide (European Parliament, 2011), therefore it is essential to look for innovative ways of financing, to prevent trade restrictions and to decrease the debts of most affected countries. In this announcement, the question on price increase that is partly caused by the cultivation of energy crops on the agricultural lands was also accepted.

Beside the issue of food supply, an issue of sustainable development is distinct where one of dimensions is ensuring of human welfare, abatement of poverty at the same time respecting the limited powers of natural resources and ever increasing environmental problems. The issue on sustainability first in the international area appeared in 1987 in the report of the World Environment and Development Commission of the UNO "Our Common Future", but widely it has been used from the Rio de Janeiro conference "Environment and Development" in 1992 where sustainable development is explained as development that ensures the satisfaction of present needs by not creating threat to the satisfaction of needs for next generations. (Rio Declaration, 1992) The international plan of actions for the 21st century *Agenda 21* was accepted there. Together with these issues, it was internationally defined that human welfare is essential including that human primary need for food is ensured at the same time respecting the limits of the eco system.

A real impulsive document for sustainable development in the international area is the Kyoto protocol established in 1997 (UNFCCC) that foresees that till 2012 all industrial countries attain the decrease in emission levels of gases creating the greenhouse effect by 5% in comparison with 1990. (Kyoto protocol, 1997) Also EU countries in this issue have undertaken even higher aims to decrease the emission of these hazardous gases by 8% till 2012, but till 2020 by 20% in comparison with 1990, to increase the part of renewable energy up to 20% in the total consumption of the EU, but for vehicles to use 10% of biofuel.

Now the year 2012 has just begun, so the achievement in this field cannot be completely evaluated. From the point of view of the scientists and practitioners, the performance of the aims in EU countries is more or less satisfactory, but worldwide in general there are substantial disagreements. The evidence is the fact that several countries have not ratified the Kyoto protocol; there are huge unsurpassable barriers between the position of the USA and China about these issues which are responsible for the 40% of the pollution of the atmosphere. The world leaders meeting in Copenhagen at the end of 2009 did not give either the answer how to solve these problems after the termination of the Kyoto protocol. (Climate Conference in Copenhagen, 2009) The proposed decrease in emission of hazardous gases from the USA is only 3-4% in comparison with 1990. The main objections of the USA and China are connected with the opinion that taking into consideration the regulations of Kyoto protocol, the economic growth of those countries will substantially be impeded.

A year later in the city of Cancun in Mexico, the idea of the establishment of the Green Climate Fund was accepted (the agreement of 190 countries), till 2020 it should contain 100 billion dollars with the idea that the money of the rich countries will be allocated to the countries that suffer the most from the climate changes. The fund will be supervised by the World Bank. It is foreseen that the rich countries should lower the emission of hazardous gases by 25-40% in comparison with 1990. (Climate Change: Post-Copenhagen …, 2010) The positive fact is that the document foresees to develop a plan how to stop deforestation of huge areas of forests, although there are no references about mechanisms, especially market restriction mechanisms how to influence that. In fact, the main success of this agreement is the attraction of the money resources of the rich countries to the solving of climate problems; this is the struggle with the consequences. The concentrating to the different kind of investments of the developed countries, for example innovative, technological solutions, is expressed to a lesser extent.

Together with the political solutions of the sustainability processes in the international area, there are scientific suggestions, prognoses and discussions on these issues. Presently a more or less uniting opinion:

1) That processes of global warming, by the decrease of a certain temperature, can cause irreversible consequences in nature, also in the national economies of many countries;
2) The amounts of fossil resources are limited, solutions for its replacement should be looked for, but there are great discussions if presently chosen alternatives are better from the point of view of the sustainability than former ones.

The competition of the cultivation of food and energy crops per area of arable land

The group of EU scientists using the Green-X mathematical model carried out a research how to use more effectively the potential of biomass to implement the set EU aims in the Kyoto protocol by examining the benefits from 3 implementation scenarios if the produced potential of energy resources is increased to 15, 25 or 30%. From the point of view of the scientists, the most cost effective way how to use biomass would be if by 2030 for heating 18% of it were used, for obtaining electric energy 12.5% and 5.4% for vehicle fuel. At the same time it is emphasized that more extensive use of the bioenergy would raise the cost for energy approximately by 20% and these costs would have to be covered by consumers. A grate attention is paid to new technological solutions that could serve as a provision to decrease the costs in the use of renewable energy, moreover, the scientists indicate that not only entrepreneurs should involve in this process with greater trust, but also banks, contractors, developers of the support schemes – government institutions etc. The coordination and integrated actions are needed among EU countries in the development of support mechanisms that would give lower transitional costs for consumers. (Economic Analysis of RES-E Support Mechanisms, 2004) The more extended use of the biomass potential in power industry raises certain concerns in the security of food production, in the existence of valuable forests and natural meadows that serve as a natural absorber of CO_2. In 2009, the group of scientists lead by *Timothy Searchinger* carried out a research using an agroeconomic world model where they wanted to find out what changes would cultivation of maize and switchgrass in huge areas in the USA create in the cultivation of other food crops in other countries of the world, with the basic idea that in other countries the forest stands and natural meadows were turned into arable lands to compensate the lack of food. The main conclusion is that in 50 years the emission of greenhouse effect gases would increase than using the fossil fuel. Cultivating the energy crop in huge areas, in the soil of forests and meadows, the depositary of the natural CO_2 would be destroyed. The conclusion of the scientists is that several decades would pass till the gains from the enlarged potential of the renewable energy overcame the negative influence. Ethanol obtained from the maize doubles the emission of greenhouse effect gases in a 30 year period. This result raises doubts to exploit huge territories for cultivation of biofuel crop. Greater attention should be paid to the use of waste products. (Use of U.S. Croplands …, 2009) Moreover, by enlarging the areas for crop cultivation, it is foreseen that the inflow of nutrients into the natural watercourses, including nitrogen. As a result, the gains of nature protection are doubtful. The research of similar character was carried out by the researcher group of Catlin Arctic Survey drawing the correlation between the price of soybeans and deforestated areas. The higher was the soybean price, the larger areas of rain forests were cut out. This mutual coherence is invoked by the increase in demand for bioethanol for which the rural territories for soybeans are converted into the fields for maize to obtain bioethanol. By decrease of the soybean offer in the world's markets, the price of that resource increases.

There is also an opinion that cultivation of crops for needs of bioenergy is not such a big competitor for food production, emphasizing that there are plenty of uncultivated lands in the world including arable lands. German scientists (Nova, 2008; Grethe, 2008; Zeddies, 2008; Baltzeretal, 2008) assess the insufficient efficiency in soil exploitation as unused potential both from the point of view of the productivity of labour and from the possible productivity potential, for example, the average crop productivity is not even close to the possible optimal level in many countries, as the optimal average productivity 6.5 - 7 t/ha can be obtained in Poland, Japan, Lithuania, Belarus, Italy, Hungary, Romania, Latvia and Ukraine. Presently the obtained productivity actually is 3.5 – 4.5 t/ha. Largely, the nonexistence of crop rotation or cultivation of crop after crop several years in succession has been mentioned as the reason for foregone productivity.

However, it must be outlined that raising productivity can demand additional financial resources and the more infertile the soil in its natural way is, the more investments are needed, in particular cases these investments are not cost effective and it is not useful to cultivate the respective crop in these areas. Partly the cultivation of energy crop could reduce that demand because, for example, in Latvia high quality soil is needed to cultivate food cereals, besides the choice of energy crops is very wide, thus there are greater option possibilities also for poorer soils by finding the most appropriate for them.

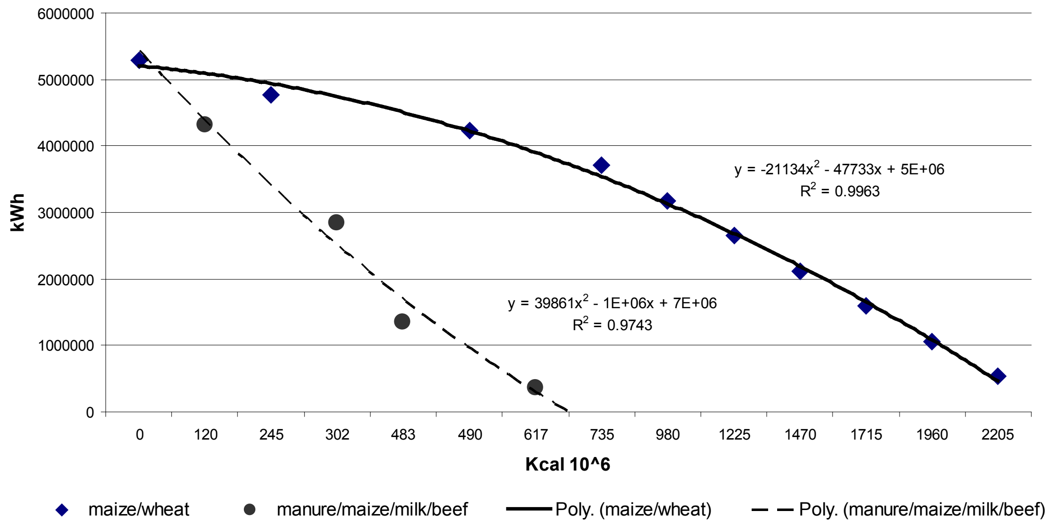
Analyses of energy and food productivity

To accept or deny the global challenge in the security of energy and food production, it is essential to evaluate this alternative at the micro level. It must be examined after what considerations the manager, farmer of the limited agricultural land resources follows.

The basis of the theory of economy is the solutions of the dilemma of limited resources. Malthusianists hundred years ago indicated to the possible collapse of common economy that was based on the limitedness of resources. However, the main essence of the resources has changed with time; land as a basic resource has been excluded from the function of production, as well as it has overgrown its meaning in production including social services that is the base for ecoservices. In the economic analyses, the social gains and loses which often directly (compensations, subsidies) influence the efficiency of production also have to be evaluated along with the economies of scale. To illustrate the previously mentioned, the authors have prepared production simulation where the results are summarized in Figure 1 with the help of production potentiality curves.

Two possible alternative scenarios have been examined. The first (in the Figure – maize/wheat) – the farmer has the choice to grow two crops – maize for energy production from biogas expressed in kilowatt-hours (kWh) or/and winter wheat for food expressed in kilocalories (Kcal). His arable fields (assumed 100ha), the farmer can sow with any of the mentioned crops. If the farmer sows only maize to obtain energy (point A), then he does not obtain food and vice versa (point B). The situations when the division of resources (land) between the crops occurs are shown between the extremities. Basically, the curve shows the character of efficient division of resources. The points to the right from the curve are not possible on the existent conditions, the points to the left from the curve are possible, but the resources are not valuably used. This is defined by the theory of economy. The second possible scenario characterizes a more complicated choice for the farmer (in the figure – manure/maize/milk/beef (among the points A and C)). He can divide the land for the production of food (milk, beef) by breeding cattle and simultaneously produce energy from manure (situation at the point B), or intensify the production of energy by allocating a part of the land for maize cultivation, approaching the point A along the curve. The results can be view in Figure 1.

The farmer exploits the land more efficiently if he produces maize or/and winter wheat. The scenario with cattle breeding substantially falls behind in estimations. Nevertheless, the livestock breeding scenario has several advantages which cannot be assessed within the model. Firstly, the dilemma of food -



Source: developed by the authors

Figure 1. **The curve of production potentiality in a farm**

energy is less explicit in livestock breeding because it provides to produce energy in the situation when the land for energy crops is not allocated. Secondly, the harmful ecological effect of cattle breeding waste (manure) is lowered. Thirdly, beef and grain in the economies of the developed countries are not strictly replaceable products that are characterized by the difference in the price for one item. Therefore, the expressed values Kcal are conditional. In a practical situation, the international market also acts, which can reduce the influence (government policy) on the situation.

Meanwhile the previously described model shows that obtaining energy only from cattle breeding manure is far less effective in obtaining production than cultivation of energy crops. Therefore, solving the issue of food supply, mixed versions are more effective than situations when only energy or food is produced. The use of cattle breeding manure in obtaining energy is sustainable from the point of view of environment maintenance and the competition for the exploitation of land resources between food and energy production. However, economically from the point of view of the cover of expenditure and business stability, the derived solutions (points between the points A and C) overall would be more effective. Therefore, at the micro level the modeling of production mix combining food and energy crops is an effective way how to achieve sustainable production and lower the risks acting in different markets (energy and food).

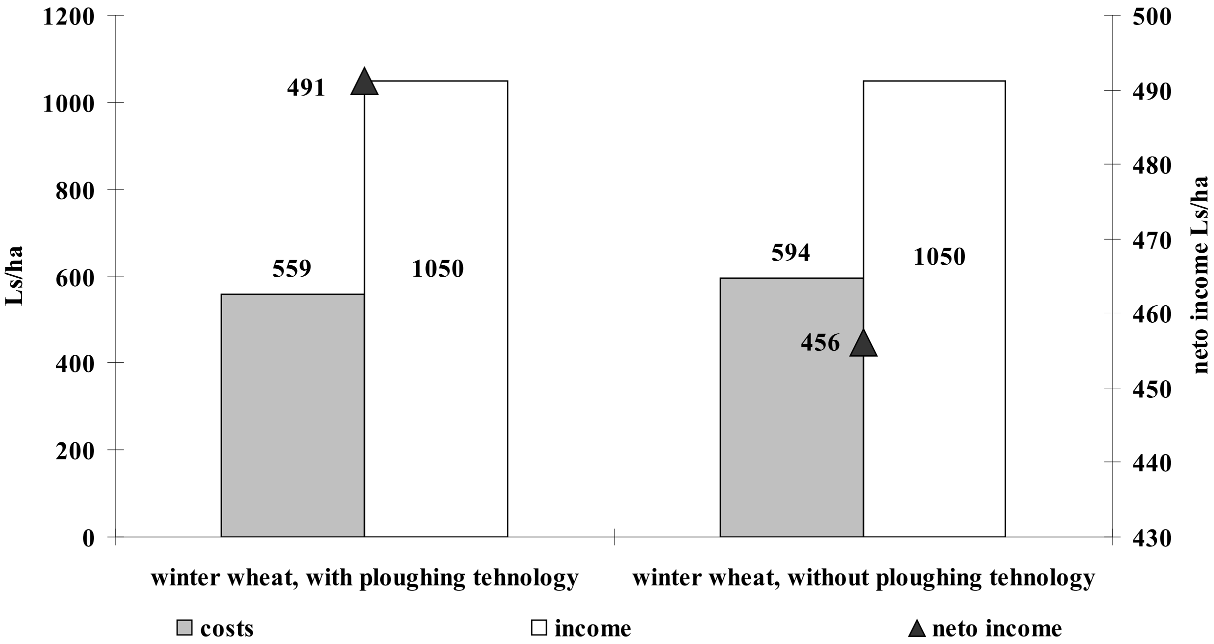
Analysis of energy and food profitability

In a real situation, the factors that define the behavior of the farmer to choose food or energy production are quite many. The complicity of the choice can be connected not only with the exploitation of land but also launching a difficult and new production related to high capital investments. Therefore, the analysis of productivity is essential, which would allow making a choice for energy production. The authors have made calculations with the aim to compare the productivity for producing maize for biogas or winter wheat for food.

Of course, the following modeling of the situation is abstract, as it foresees the obtaining of energy only from maize; the limitations of the land are not taken into account. It is assumed that all other expenses related to the production of biogas are 0.07 Ls kWh^{-1} that includes both capital and variable (without substratum) and administration costs. The main remark – the production unit of the biogas has to recover itself, as well as it must fulfill the agreement with the society on realization of electric and thermal energy. Thus the farmer together with the decision to produce biogas has solved this dilemma at least for 10 years. However, the margin of profitability will cause sharp development of biogas production units as well as increase in land price.

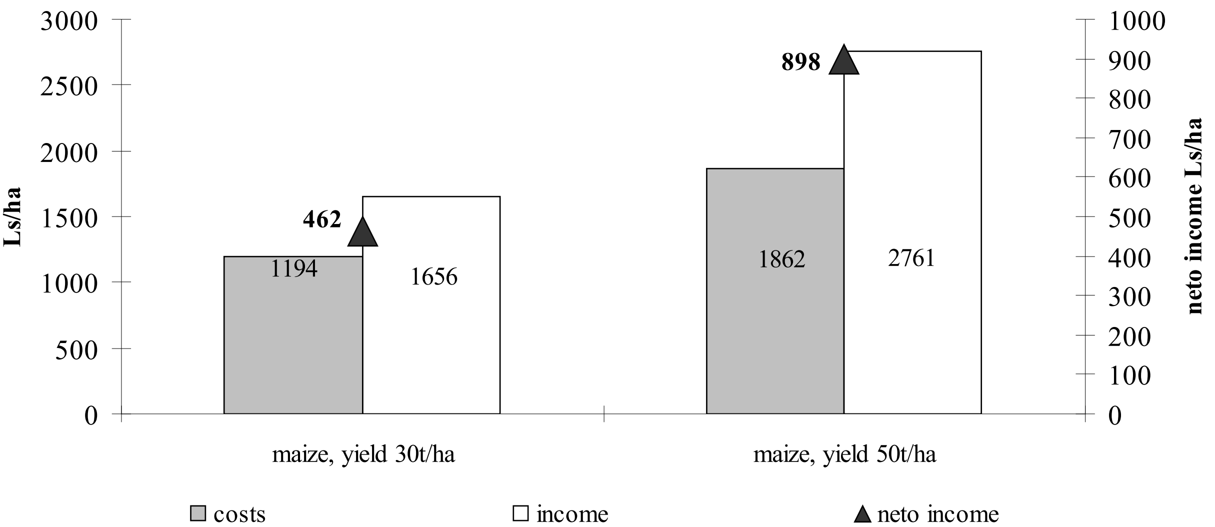
To compare expenses and profitability, an absolutely extreme situation has been chosen. Firstly, the productivity of winter wheat is high 7t ha^{-1}. Secondly, the biogas production unit distributes only electric energy. The sales price of winter wheat – 150 Ls t^{-1}. The results of the modeling of winter wheat profitability are shown in Figure 2.

The income from the sales of winter wheat in both cases shown in Figure 2 is equal because the sales price and harvest amounts from hectare are equal. Though there is a difference in costs that can be explained by different technologies – with ploughing and without ploughing. Therefore, a difference in net income appears that is made by subtracting cultivation costs from sales income. Administration costs are included as a constant sum of 6 Ls per hectare.



Source: based on the calculations of the authors

Figure 2. **Costs and income of winter wheat cultivation**



Source: based on the calculations of the authors

Figure 3. **Costs and income of maize cultivation**

So the income from hectare ranges from 456 to 491 Ls ha^{-1}.

The income of maize cultivation differs if it is cultivated to obtain bioenergy, as different cultivation technologies gave different results that is represented not only in costs, but also in the income. Thus by the productivity of 30t ha^{-1} of the green mass, it is possible to produce 11 117 kWh$_{el}$ of electric energy, but out of 50t of green mass substratum – 18 528 kWh$_{el}$. TES efficiency for electric energy is 35%. The electricity purchase tariff is about 0.14Ls/kWh. In the power unities, that would be 1.39 - 2.32 kW ha^{-1}. Such a high fluctuation only indicates that if it is not possible to get high maize yields, other energy crop should be found which would provide higher amounts of energy and lower costs. Naturally, the net income is also varied from 462 to 898 Ls ha^{-1}.

By high productivity of winter wheat (7t ha^{-1}) and high prices of cereals (150 Ls t^{-1}), the decision to build a biogas production unit is not unambiguous. If maize productivity is 30t ha^{-1}, then extra risks the farm should undertake are not compensated; whereas by the productivity of 50t ha^{-1} such a decision can be considered as reasoned.

Conclusions

Internationally widely the issues related to the food supply security for world inhabitants and the necessity of change of energy resources with renewable have been updated at the same time respecting sustainable development, although there are several substantial disagreements in solving these issues especially that are related to the emissions of greenhouse effect gases and their reduction.

It is proved by the scientific studies that the cultivation of energy crops reduces the arable areas allocated for food and to compensate that forest areas are exploited, which is in conflict with the terms of sustainability. Moreover, it is emphasized that in many countries in the world, including Latvia, the potential of arable lands is not effectively used, as possible optimal productivities are not gained, there is also a proportion of unused arable lands.

The obtaining of energy only from cattle manure is less effective in production output than cultivation of energy crops. At the micro level, combining cultivation of food and energy is an effective way how to reach sustainable production and lower the risks by acting in different markets (energy and food).

High prices of cereals can be a sufficient reason to make energy production from maize less attractive. However, in absolute numbers, at present, the cultivation of energy crops to obtain electric energy in Latvia is more profitable than production of food.

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RISK MANAGAMENT IN RENEWABLE ENERGY PRODUCTION

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Abstract
Even though the activities of an individual have always been subject to risks, the understanding of risk and its role in the society at the turn of the 20th and 21st century have become the issue of theoretical and practical importance and are closely connected with the ideas of two sociologists, U. Beck (1999) and A. Giddens (2002). The issue of risk management has not lost its topicality, therefore an increasing number of studies apply risk evaluation and risk management methods. A wider attention to the renewable energy production is drawn in the context of forecasted exhaustion of the fossil energy resources, the increase in their prices and energy dependence. Consequently, the scope of research in the field of renewable energy production has broadened. This paper summarizes the risk management studies in renewable energy production and proposes risk classification, risk management cycle and risk management options for the management of renewable energy production risks in Latvia.
Key words: risk, risk classification, risk management cycle.

Introduction

European Union (EU) consistently works on setting up a common energy policy with an important place allocated to the renewable energy production, energy efficiency, sustainable use of resources, and energy security and independence. The new Directive on renewable energy (Directive 2009/28/EC of the European Parliament and of the Council) sets ambitious targets for all Member States: the share of energy from renewable sources in EU reaching 20% by the year 2020 (8.5% in the year 2005), and a 10% share of renewable energy specifically in the transport sector (Directive 2009/28/EC, 2009). To reach this common goal, each member state has to increase the amount of renewable energy production and exploitation as a source for electricity, heating, cooling, and transportation. In the year 2010, renewable energy composed 37% in the total structure of energy in Latvia, with a target of reaching 40% in the year 2020.

Although researchers of the Latvia University of Agriculture have a certain experience in working with risk determination and assessment issues in various fields of agriculture, veterinary medicine, food science, etc., the field of renewable energy production is rather new and is scantily explored, therefore we should adopt the experience of other countries, for example, the USA (Rausser, M. Papineau, 2008) and the UK (Froggatt, Lhan, 2010), and of organizations such as United Nations Environment Program (Financial Risk Management.., 2004).

The research aim is to summarize risk classification and risk management approaches in the context of renewable energy production.

Materials and Methods

There are several definitions of the notion of risk in scientific literature (Hardaker, Huirne, 2004; Renn, 2008; Pettere, Voronova, 2004; Šuškeviča, 2005; Baoding, 2011; Definitions of Risk, s.a.; etc.). Some authors define it as a probability, others as consequences (positive or negative), some authors consider that risk is the combination of probability and consequences. The authors of the present paper define the term 'risk' in the following way: risk is the multiplication of the probability of an event occurrence and its significance level of potentially unfavourable consequences. There is no unanimous opinion neither regarding the definition of 'risk' nor regarding the classification of risks. Risks are difficult to group because of their close mutual links and substitution. John Maynard Keynes (1930; 1937) was the first scientist who attempted to divide risks into three groups:

– risk of a loan taker;
– risk of a creditor;
– inflation risk (Arhipova, Arhipovs, 2005b).

Different risk classifications and risk groups appear in the publications. Regarding the location of risks, they are divided into internal and external (Pettere, Voronova, 2004). Likewise A. Giddens (1999) applied a similar risk division, grouping them into external risks and manufactured risks caused by one's own activities. The risk as a decision is considered to be an internal risk, but the risk as an event refers to external risks.

As far as the origin of risks is concerned, risks are divided into subgroups, which, according to the aim of the classification, might be either all-embracing or specific. For example, 'RiskMetrics Group' has identified a broad spectrum of 12 risks that includes market, management, environment, social, accounting legislative, credit risks, etc. (RiskMetrics Group, 2008). Recently the research on financial risk management has become more common including market risks, liquidity risks, credit risks, operational risks, legal risks, etc. (Crouhy, Mark, 2000).

Table 1.

Approaches of Risk Classification

No.	Risk classification feature	**Types of risks**
The cause (source) of risk		
1.	Type of business	1.1. Financial (credit) risk 1.2. Production risk 1.3. Investment risk 1.4. Innovation risk 1.5. Market risk 1.6. Legislative risk 1.7. Insurance risk 1.8. Transport risk
2.	Cause of risk	2.1. Business risk 2.2. Risk of manager's personality 2.3. Risk of insufficient information
3.	Location of the cause	3.1.Internal risk 3.2. External risk
4.	Type of the cause	4.1. Objective risk 4.2. Subjective risk
The risk force subject		
5.	Scale	5.1. Local (endemic) risk 5.2. Regional risk 5.3. National risk 5.4. International risk 5.5.Global risk
6.	Included economic subjects	6.1. Individual risk 6.2. Group risk
The risk conditions		
8.	Insurance opportunities	8.1. Insured risk 8.2. Risk without insurance
9.	Impact time period	9.1. Short-term risk 9.2. Long-term risk
10.	Time criterion	10.1. Past risk 10.2. Current risk 10.3. Future risk
11.	The significance level of risk consequences	11.1. Acceptable risk 11.2. Critical risk 11.3. Disaster risk
12.	Diversification level	12.1. Common risk 12.2. Specific risk
13.	Forecast opportunity	13.1. Forecast risks 13.2. Risk which is impossible to forecast

Source: created by the authors on the basis of Pettere, Voronova, 2004; Stanka, 2004; Crouhy, Mark, 2000; Olivier, s.a.; Merna, Al-Thani, 2005

Besides the above mentioned classifications, risks could be grouped according to the scale, insurance opportunities, economic subjects, operational length, time criterion, legal criterion, etc. (Pettere, Voronova, 2004). After having examined risk classification approaches, the authors of the present paper created their own risk classification consisting of three groups (Table 1):

1. risk classification according to the cause (the source);
2. risk classification according to the risk force subject;
3. risk classification according to the risk conditions.

Each of the groups contains subgroups or risk classification features that serve as the basis for the selection of the group.

The type of risk classification depends on the aim, the branch, and the context of risk management. Apart from the ones described above, there is a risk classification approach, which is based on risk force subject. The PEST analysis method is the most commonly used method; it comprises political, social and technological aspects. The PESTEL method includes environmental and legislative aspects in

Table 2.

General classification of risks in renewable energy production

Risk group (cluster)	Risk
1.Personnel	1.1. Responsibility of the personnel 1.2. Qualification and experience 1.3. Work safety
2.Production	2.1. Quality of resources 2.2. Stability of production cycle 2.3. Regular supply of resources 2.4. Connection with the state electricity network 2.5. Utilization possibilities of the produced heat and their stability 2.6. Accessibility of service for technical equipment
3.Property	3.1. The outer security of the energy production plant and other production facilities 3.2. Credit risk 3.3. Fire security
4.Environment	4.1. Storage of production resources 4.2. Transportation of production resources 4.3. Storage of waste from production of energy 4.4. Further use of waste from production of energy
5.Legislative	5.1. Changes in energy policy 5.2. Changes in the purchase tariffs

Source: made by the authors

addition to political, social and technological aspects (SWOT&PEST Analysis, s.a.). The method STEEP is less common, it contains political, economic, social, environmental and technological factors (Mazareanu, 2007). The method STEEPLED comprises political, economic, social, environmental, legislative, ethic and technological factors (STEEPLED Analysis, s.a.). The analysis of risk management research in the field of producing renewable energy shows that the risk classification in this field is mostly related to the cause of risk. The dominating groups among others are technological, environmental, legislative, financial and investment risk groups (Olivier, s.a.; Financial Risk Management, 2004; Froggatt, Lhan, 2010.; Ferraris, s.a.); less common are such groups as social, macroeconomic, resource, short-term and long-term operating risks and reputation risks (Financial Risk Management, 2004; Froggatt, Lhan, 2010; Aragonés-Beltrán, Pastor-Ferrando, 2009). The above mentioned principles have been used in the present research to design the risk assessment system by classifying the risks into 5 basic groups on the basis of the cause of risks – personnel, production, property, environmental, and legislative risks.

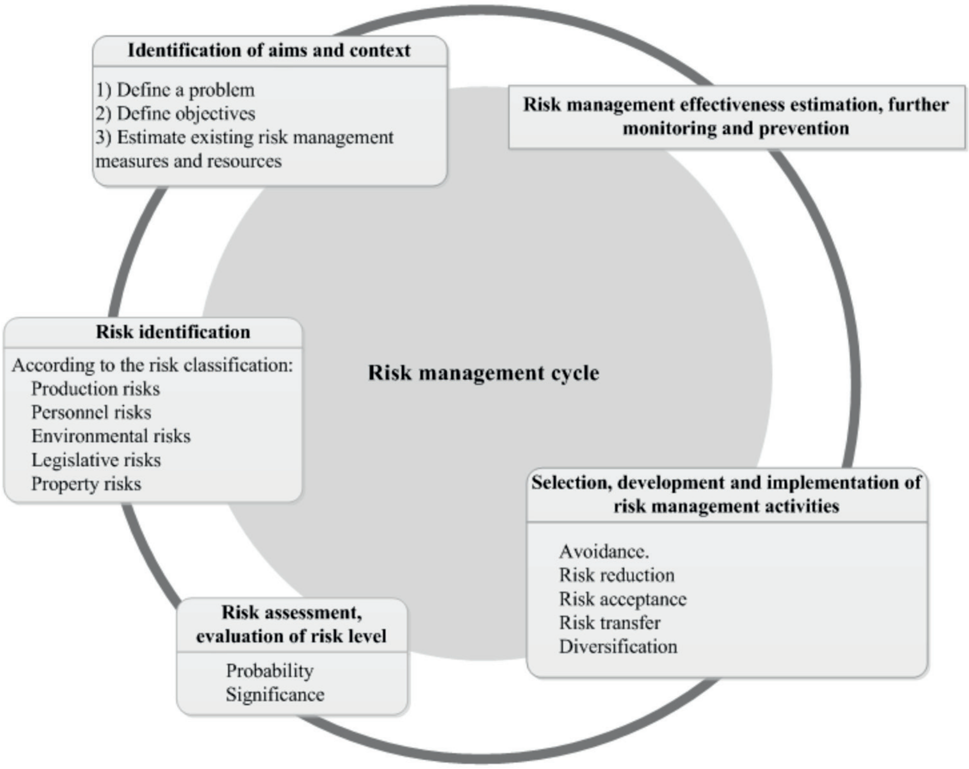
According to the literature review, the authors tried to create a general classification of risks in renewable energy production, which could be extended or modified according to the specifics of the particular field of renewable energy production. For example, in biogas production, under the Production group there would be such risks as 'Quality of biomass' instead of the generalized 'Quality of resources', but in the Environmental risk group 'Utilization possibilities of the produced heat and their stability' instead of 'Further use of waste from production of energy', etc.

Results and Discussion

Risks are manageable using various methods, which allows forecasting the probability of risks and taking measures to minimize the risk level. Risk management is a set of methods, approaches and actions with the help of which it is possible to forecast risks at a certain level and to develop action plans for risk prevention or for reduction of negative consequences (Rurāne, 2002). Risk management in a company should be implemented as an ongoing process or the so-called risk management cycle. The risk management cycle (see Fig. 1) comprises 4 basic elements: identification of aims and context, identification of risks, assessment of risks (assessment of risk level), and implementation of risk management activities. Risk monitoring and prevention are implemented in all stages of the cycle; risk monitoring and the analysis of effectiveness of the implemented activities are important, particularly, after the completion of risk management activities.

Several approaches might be applied to risk assessment and risk level evaluation that can be divided into 3 groups: qualitative, quantitative and semi-quantitative (Šantare, Rivža, 2007).

– Qualitative research methods are applied to assessment either of economic results or forecast of possible consequences which do not have quantitative features and scales. These methods are evaluated by discrete quantity 1 and 0, 'yes'or



Source: created by the authors on the basis of Trigilio, 2006; Olivier, s.a.; Guide to Risk.., 2004; Špoģis, 2005

Figure 1. **Risk Management Cycle**

'no', etc. Intellectual, dispositive and other types of risks belong to this group (Špoģis, 2005). This type of risks is assessed by means of decision making (hierarchy analysis method, analytical network method) (Saaty, 2010) and expert methods (Delphi method) (Pettere, Voronova, 2003).

- Forecasts of consequences and economic assessment of risk factors might be based on the data accumulated by entrepreneurs, publications and statistics. If the amount of the available data is sufficient, it is possible to apply quantitative methods based on the probability theory, mathematical statistics and other appropriate methods (Špoģis, 2005).
- Semi-quantitative risk management methods are used to express the qualitative assessment of experts with a quantitative indicator, i.e. risk level, and it is determined applying the risk analysis taxonomy. This method is used to assess a wide range of risks.

The methods of risk assessment in the field of renewable energy depend on the aim and context of the specific risk assessment. The research is frequently related to investment risks, therefore quantitative risk assessment methods are most commonly used; however, semi-quantitative methods can also be applied.

After the identification, the measures should be developed and implemented to further management of the identified and assessed risks. The development of measures is based on the analysis of risk management options. Theoretical sources (Sparrow, 2000; Trigilio, 2006; Olivier, s.a.; *Guide to Risk*.., 2004; Špoģis, 2005; Pettere, Voronova 2003) mention 5 options.

1. Avoidance is a commonly used option in risk management and it means the avoidance of the risks causing significant destructive consequences. This option envisages elimination of the causes that could lead to serious losses in an enterprise. Thus, production and economic conditions are created to prevent the probability of risk occurrence – either discontinuing the production and leaving the area of business subject to risks, or making political decisions of banning certain business activities (e.g., production of nuclear energy in a country) etc.
2. Risk reduction – this option reduces the likelihood of the risk occurrence or the amount of risk consequences, or the risk level (both probability of risk occurrence and the amount of risk consequences). The application of this option is necessary when:
   - risk occurrence probability or loss occurrence probability is sufficient enough and there are safe methods to reduce the loss;
   - the amount of possible loss is negligible.

The method envisages the development of preventive measures decreasing the probability of risk occurrence and warns (if performed regularly) about the emergence of risk causes. The application of this option is reasonable if costs do not exceed the gains.

3. Risk acceptance – this option includes accepting the losses of the risk consequences and covering the expenses from resources of an enterprise. This option is applied when:
   - probability of loss occurrence is negligible;
   - the amount of potential losses is not large (they can be paid from regular financial gains).
4. Risk transfer – one party which is subject to risk finds a partner that can take the responsibility of possible risks. The consequences of risks are transferred to an insurance company or another company or organization on the basis of a contract.
5. Diversification – revenues are obtained from different mutually unrelated business activities (European Commission, 2001). Revenues from one or several business activities cover the losses of unfortunate business in the given time period. The risk of the business failure is reduced. The diversification as the risk reduction strategy increases the total production costs, since purchase and maintenance of various equipment and machinery increase the amount of the fixed costs in the company (Šantare, Rivža, 2007).

Initial research of risk management assessment options (Rivža, 2011) in the context of renewable energy production shows that specific features of a risk group should be taken into account when selecting a preferable risk management option. For example, property risks require risk transfer by means of property insurance, but legislative risk management requires risk monitoring since there is no other option from the point of view of a renewable energy producer. As regards production, personnel or environmental risks, they refer to risk reduction and, in some cases, risk acceptance.

Conclusions

The type of risk classification depends on the aim and the context of risk management. Risks can be divided into three classification groups: according to the cause (the source), according to the risk force subject, and according to the risk conditions.

Risk classification in this field is mostly related to the cause of risk. The dominating groups among others are technological, environmental, legislative, financial and investment risk groups, less common are such groups as social, macroeconomic, resource, short-term and long-term operating risks and reputation risks.

The methods of risk assessment in the field of renewable energy depend on the aim and context of the specific risk assessment. The research is frequently related to investment risks, therefore quantitative risk assessment methods are most commonly used; however, semi-quantitative methods can also be applied.

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LEARNING AND INNOVATION IN NETWORKS: THE CASE OF BIOGAS PRODUCTION IN LATVIA

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Abstract
In this paper we explore how learning is framed in multifunctional and hybrid networks that simultaneously deal with market exchange, knowledge transfer, policy making and technical innovation. Following Erving Goffman we define frames as shared understandings (ways of thinking and ways of doing) that actors develop jointly as they encounter each other for a common purpose. We analyse this process in two hybrid agricultural networks that are studied in SOLINSA project: the Latvian fruit growing network and the biogas production network. Both networks consist of diversity of actors and sub-groups: farmers, researchers, policy makers, technological companies, investors, retailers, consumers, etc., and they perform various functions that redefine urban-rural relations. In introduction we review network and social learning theories to position learning in complex networks. Social learning happens in social context which forms a social frame. In the second part we provide description of both networks – their composition, functions, actor relations and knowledge flows using SNA tool (smart network analyser). In the final part we discuss how common frames of learning are built. What are learning challenges and solutions in hybrid networks and how are conflicts overcome? We test hypothesis that frames of learning are constructed according to field of operation (food, non-food production), and this happens differently according to the type of learning (formal, informal, nonformal), operational level of learning (from local to global) and network cohesion. Local and international contexts both influence frames of learning. We argue that in networks there are various frames co-existing and overlapping: intro-group frames, inter-group frames, the network-level frames, and extra-network frames. We also examine what boundary issues of economic nature (e.g. common market interests), technical nature (e.g. adoption of new technology), cultural nature (e.g. protection of local varieties) and cognitive nature (e.g. use of common learning tools) stipulate knowledge framing.
Key words: frames of learning, hybrid networks, innovation, boundary interaction.

POSSIBILITIES FOR BIOGAS PRODUCTION DEVELOPMENT ON THE LLU TRAINING AND RESEARCH FARM „VECAUCE"

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Abstract
The training and research farm "Vecauce" is a multi-branch farm. Scientific researches both in agriculture and in problem industries are introduced and tested on the farm. One of them is the power industry. The construction of a modern cowshed for 500 milk cows was started in 2008. Next to it, a biogas facility with an electrical capacity of 260 kW was also constructed. It was the first biogas facility in Latvia in which manure and the green mass of crops were used as a substrate. More than 50 biogas facilities are presently operating in the country. The training and research farm "Vecauce" has planned to double or triple the output capacity of its biogas facility. A calculation, performed by academician of the Latvian Academy of Sciences A.Kalniņš, based on a methodology employed in Germany – KTBL (*Kuratorium für Technik und Bauwesen in der Landwirtschaft)* – was used. It is possible to reach an electrical capacity of 510 kW or 710 kW by intensifying agricultural production, restructuring it, or cooperating with farmers of Auce municipality.
Key words: biogas, biogas production.

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