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Study on Agriculture Decision-Makers Behavior on Sustainable Energy Utilization

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Abstract Phytomass cultivation for energy use is increasingly popular in Europe for high profits guaranteed by subsidy. Although public interest in ecology is on an increasing level, direct combustion is still preferred even though scholars have been warning about formations of hazardous compounds for a long-time. However, the reduction of subsidies would negatively affect an already bad situation in Czech agriculture, since most farmers became fully dependent on subsidies due to quotas, restrictions, and other unequal business conditions in European Union. It was proved in a commercial scale that an alternative phytomass energy utilizing technology consisting of steam explosion and subsequent anaerobic fermentation may be run solely on the waste heat without any further addition of chemicals. Behavior analysis of present and future agriculture decision-makers showed that none of the farmers who visited the facility cared about ecological consequences. On the other hand, ost students from the Faculty of Agriculture and the Faculty of the Economy answered the questionnaire with higher environmental responsibility. We assume this is caused by high average age of farmers in Czech Republic who are more aware of the ongoing economical difficulties and perceive differently the risk of higher acquisition costs.

Keywords Agriculture · Decision-makers behavior · Energy utilization

Introduction

The sustained European interest in miscanthus suggests that this novel energy crop deserves serious investigation as a possible candidate biofuel crop in North America

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and elsewhere, perhaps alongside switchgrass (Scurlock 1998). Displacement of carbon released by burning fossil fuels to produce electricity and sequestration to the soil showed that 9 % of the total European C emissions in 1990 could be mitigated by growing and burning Miscanthus for electricity production (Clifton-Brown et al. 2004). Without irrigation, autumn yields of 10–25 t ha^{-1} (dry matter) can be expected. The quality of miscanthus biomass for combustion is in some respect comparable to woody biomass and normally improves by delaying harvesting until the spring, although harvestable yields are thus reduced by 30–50 % compared with autumn yields (Lewandowski et al. 2000). However, Hallgren and Oskarsson (1998) state that the main problem of combustion of miscanthus biomass is the low ash melting point. Sintering of ash under fluidized-bed gasification may cause agglomeration (or, at worst, alkali-induced defluidization). Miscanthus ash showed clear sintering tendencies at temperatures as low as 600 °C, compared with reed canary grass and willow (the latter of which was inert up to 900 °C). This may be due to the combination of relatively high silica content in miscanthus, together with potassium and fluxing agents such as iron. In addition it is warned that volatile organic compounds and polycyclic aromatic hydrocarbons are produced in case of incomplete combustion (Chagger et al. 1998; Jenkins et al. 1998; Khan et al. 2009). The goal is to replace resource-intensive and environmentally degrading products and practices with those that are more environmentally benign (Gliessman 2009). Previous experiences (Maroušek 2012; Maroušek et al. 2012) made me formulate the hypothesis whether the newly developed complex technology of steam explosion adapted for linkage to the most common agriculture biogas stations (1 MWh) may offer more sustainable, ecological and profitable alternative for energy production from *Miscanthus sinensis* than conventional combustion. Physiological characteristics are important (Fukuzawa et al. 2012). de Vrije et al. (2002) achieved in production of fermentable substrates from miscanthus excellent results of 77 % delignification, a cellulose yield of more than 95 and 44 % hydrolysis of hemicellulose. However, the intensive chemical pretreatment of 12 % NaOH can not be considered as part of sustainable agriculture. Decision analysis of current and future agriculture decision makers (present farmers and students of the Faculty of Agriculture and the Faculty of Economy at the University of South Bohemia) was carried out to estimate the trends.

Materials and Methods

Miscanthus Straw

Approximately 18,500 plants of *Miscanthus sinensis* (*giganteus* variety) survived from 20,000 of 7–8 cm rhizomes ha^{-1}, in 3rd year. 14.2 t ha^{-1} was harvested on 10 of May 2010 in Hrad, Czech Republic (GPS: +49°21′4.97″, +17°22′49.26″). The loamy filed ($pH = 5.7$, $P = 97.9$ mg kg^{-1}, $K = 109.2$ mg kg^{-1}) is annually fertilized with 120 kg of urea (46 % N) ha^{-1}, which represented 55 kg N ha^{-1}, 200 kg hyperphosphate (26 % P_2O_5, 3 % Mg) ha^{-1} representing 52 kg P_2O_5 ha^{-1}

with 6 kg of Mg, and 90 kg potassium salt (61 %) ha^{-1} representing 55 kg K_2O ha^{-1}. The phytomass was pelleted using the JGE 120 (PCC Ltd., Czech Republic) into 6 mm rolls (960 kg m^{-3}, TS 93.5 %, VS 92 %, acidic-detergent fiber 37 % VS, acidic-detergent lignin 17 % VS, 16.1 MJ kg^{-1}VS, labile pool 1 of carbon 14.9 %, labile pool 2 of carbon 36 %.

Inoculate

The inoculate (total solids 1.2 %, volatile solids 0.3 %, density 1,157 kg m^{-3}, $pH_{(38\text{-}51\ °C)} = 6.6968e^{0.0007T}$ with an R^2 value of 0.98, where T is in °C, N = 0.8 % TS, P = 0.4 % TS, K = 0.3 % TS, Ca = 0.2 % TS, C_{tot} = 8.7 % TS, biological oxygen demand in 5 days at 20 °C ($BOD_{5,20}$) = 5,213 mg L^{-1}, chemical oxygen demand by potassium dichromate (COD_{Cr}) = 5,706 mg L^{-1}, acetic acid = 405.3 mg L^{-1}, propanoic acid = 7.2 mg L^{-1}, isobutyric acid = 0.2 mg L^{-1}, butyric acid = 0.2 mg L^{-1}, caproic acid = 0.3 mg L^{-1}, and other volatile fatty acid concentrations were below the limit of detection) was obtained from the BGS Nedvědice 1, from a solid batch fermentation process involving maize silage, fresh livestock manure, livestock manure that had been stored for 6 months and residue from a previous batch in a proportion of 12:1:1:6, in Nedvědice (Czech Republic) and stored in 2,000 L plastic barrels at 4 °C until needed.

Steam Explosion

The pellets were subjected to the technology of steam explosion (Biomass technology a.s., Czech Republic) working in scale of 300 kg VS h^{-1}. The technology may be called sustainable while it is fully run by the biogas station cogeneration unit combustion engine flue gases (490 °C). Therefore it profitably and allows turning waste phytomass into increased methane yields and therefore sustainable energy. The technology (Fig. 1) consists from the under-hot-water grinding apparatus (80–90 °C) which is warmed by the waste heat from the high-pressure reactor. In the grinding apparatus the pellets loose their form and are pulverized into 3 mm particles, while the air and other intercellular gases are removed and the most easily hydrolysable organic matter and also some minerals are dissolved in the liquid fraction (Fig. 2). In addition, warming of the mash reduces the pressure fluctuations in the following continuous high-pressure reactor ended with the expansion tourniquet, which performs single 0.3 L explosion in 0.11–0.09 s.

Anaerobic Fermentation

Samples of the rapeseed straw pellets steam exploded under different conditions were inoculated in a ratio of 20:1 VS and diluted with rain water to 10 % to meet the operating standards of commercial scale biogas station. Subsequently, they were subjected to 40 days of anaerobic fermentation (40, respectively 50 °C) in a set of fully automatically monitored (temperature, pH, CH_4, CO_2, O_2 and H_2S) batch reactors with two working volumes (fermentation and secondary fermentation to

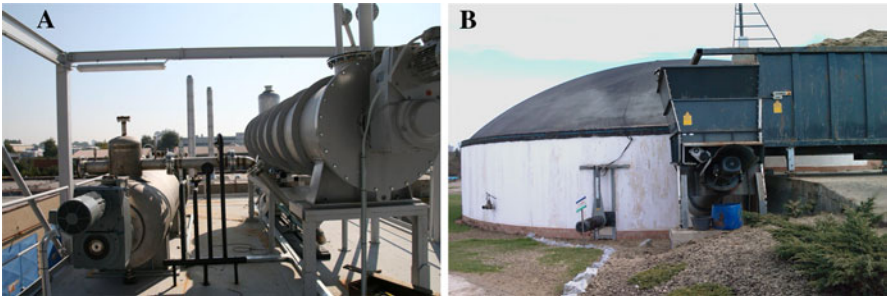

Fig. 1 **a** The technology of steam explosion (Biomass technology a.s., Czech Republic) working in the operating scale of 300 kg VS h^{-1} is run by the waste heat from the cogeneration unit combustion engine hot flue gases (490 °C) without any further addition of energy or chemicals, which makes it completely sustainable. The technology consists from the under-hot-water mill (80–90 °C, located on the *left*) and the high-pressure reactor (on the *right*) leading to the expansion tourniquet, where the real steam explosion takes place. The phytomass pretreated by the steam explosion is subsequently subjected to the anaerobic fermentation and profitably increases the methane and heat yields. **b** Standard 1 MW biogas plant which is run in many farms all over Europe

monitor the fermented material) of twice 70 L (diameter 40 cm, height 60 cm), (Stix Ltd., Czech Republic), which were operating at 2 rpm.

Analytical Methods

Elemental soil and inoculate analysis were conducted externally (ÚKZÚZ S.p.A., Czech Republic). TS and VS were determined by OV400 oven (Memmert GmbH, Germany) and an LH 06/13 muffle furnace (Fisher Scientific Ltd., Czech Republic) according to the method developed by the U.S. Environmental Protection Agency (2001). The amounts of acidic-detergent fiber and acidic-detergent lignin were determined with the Fibertec 1020(M6) fiber analyzer (FOSS Ltd., Denmark) based on the improved method of Van Soest (1963). The heat values were determinate using auto-calculating bomb calorimeter (CA-4AJ, Shimadzu). The proportions of the pools of carbon were determined by the acid hydrolysis (H_2SO_4) approach according to Rovira and Vallejo (2002) modified by Shirato and Yokozawa (2006), using the automatic high sensitive N/C analyzer (NC-90A, Shimadzu). The pH and temperature were measured using the CyberScan 600 multi-meter (Chromservis Ltd., Czech Republic). The $BOD_{5,20}$ and COD_{Cr} were measured according to the method of Sawyer et al. (2003). Acetic, propionic, isobutyric, butyric, isovaleric and caproic acids were analyzed using the 5890 Series II Gas Chromatograph (Hewlett Packard, Palo Alto, California, USA) equipped with a flame ionization detector (300 °C) and a DBwax column (30 mm × 0.25 mm × 0.25 μm). Helium was used as the carrier gas at a flow rate of 40 μL s^{-1}, temperature was set to 50 °C, the flow rate of nitrogen 30 mL min^{-1}, the injector was used in split mode and the injector port temperature was 250 °C, all J&W Scientific Inc., Folsom, California, USA. The gas chromatograph oven temperature was programmed in the following manner: the temperature was held steady at 50 °C for 2 min, increased at a rate of 10 °C min^{-1} for 20 min and then held at 250 °C for 8 min. The JSM-6510 LA analytical

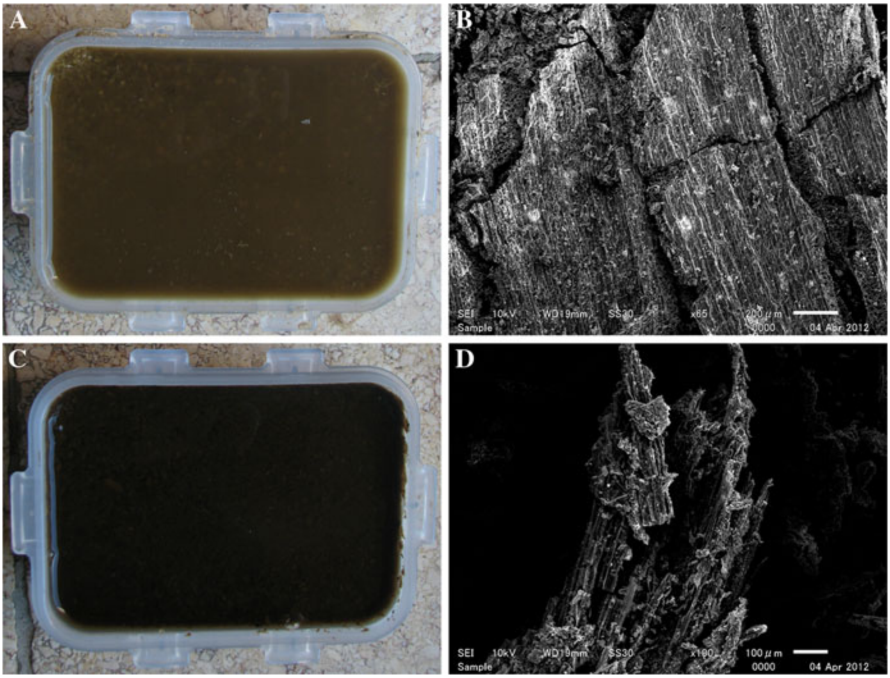

Fig. 2 **a**, **b** The result of under-hot-water grinding apparatus (80–90 °C) on *Miscanthus sinensis* previously pelleted into 6 mm rolls. The pellets lost their form being pulverized into less than 3 mm particles while the air and other intercellular gases were removed and the most easily hydrolysable organic matter and also some minerals were dissolved in the liquid fraction. The scan from electron microscope shows that the rigid lignocellulose structure did not loose its recalcitrance form of blocks. **c**, **d** The impact of steam explosion on previously pelleted and hot-water macerated substrate. It is obvious that the lignocellulose structures are partly cleaved which will allow deeper and faster anaerobic fermentation. Scans from the electron microscope were coated with 10 nm of white gold, accelerating voltage of 10 kV, WD20 mm, SS30 at 200 μm (**b**), respectively 100 μm (**d**)

scanning electron microscope (JEOL, Japan) was used to observe the inner structures of the phytomass from the upper electron detector (SEI) at an acceleration voltage of 10 kV. To prevent charging up of the surface, samples were coated with approximately 10 nm of white gold (Au + Pb) with the vacuum evaporation method using a JFC-1600 sputtering device (JEOL, Japan). Combustion analysis of the substrate was kindly outsourced by College of Chemical Technology, (Prague, Czech Republic).

Behavior Analysis of Decision-Makers

Three samples were analyzed for the decision-making analysis. First sample consisted from 27 farmers predominantly from South Bohemia (south of Czech Republic), who visited the facility plus another 50 farmers who were personally offered to come. The age was analyzed according to the standardized method of Eurostat (European statistics authority), 15–29 years: 4 %, 30–44 years: 27 %, 45–59 years: 61 %, over 60 years: 8 %. Farmers had mostly secondary education

(55 %), followed equally by higher education (23 %) and basic education (22 %). Second and third sample were the future decision-makers, students of the Faculty of Agriculture (311) and students of the Faculty of Economy (207) at the University of South Bohemia, both 100 % in the range of 15–29 years. First key question in the questionnaire asked about the awareness of negative ecological impacts of direct combustion. Summarizing all the basic environmental and financial data, the second key question was whether to invest into more environmentally friendly alternative, provided that it requires higher acquisition costs, provides greater profitability and sustainability.

Data Analysis

The data obtained were plotted by online curve and surface fitting software (zunzun.com, USA). The lowest sum of squared absolute error reached and lowest root mean squared error were the main fitting criteria.

Results and Discussion

Combustion analysis of the substrate combustion at 450 °C detected 1.703 ± 0.02 m^3 CO_2 VS kg^{-1}, 0.006 ± 0.03 m^3 SO_2 VS kg^{-1}, 0.052 ± 0.005 m^3 N_2 and 232.9 ± 17.4 polycyclic aromatic hydrocarbons ml kg^{-1}, at 500 °C 1.68 ± 0.01 m^3 CO_2 VS kg^{-1}, 0.006 ± 0.04 m^3 SO_2 VS kg^{-1}, 0.05 ± 0.004 m^3 N_2 and 209.4 ± 16.8 polycyclic aromatic hydrocarbons ml kg^{-1} ($n = 6$, $\alpha = 0.05$). While polycyclic aromatic hydrocarbons belongs to the group of persistent organic pollutants suspected of carcinogenic, such data confirmed the assumptions about negative environmental impacts of combustion based on previous measurements. Politically supported and therefore economically advantageous (donations) co-combustion with coal was not analyzed, because farmers already stopped doing it. The ethics was combined with the practice, as they understood that the outgoing ash is not suitable for agricultural land. Processing of the substrate by the technology of anaerobic fermentation showed that from the technological point of view (if we do not want to distort the conditions of sustainability and supply additional energy) the performance of the steam explosion technology pretreatment was limited by the amount of remaining waste energy. It was verified that the hot flue gases (490 °C) from standard 1 MW agriculture biogas station allows maximum reactor pressure of slightly above 2 MPa, which was also the case of the study presented. Numerous series of samples of *Miscanthus sinensis* pretreated by the steam explosion under different conditions were performed to analyze the strength of the technology. The intensity of pretreatment was measured as degradation of the organic components in response to pressure and volatile solids (Fig. 3). Degradation of the organic components was determined by the acid hydrolysis approach according to Rovira and Vallejo (2002) modified by Shirato and Yokozawa (2006) expressing the increase in the proportion of labile pool of carbon 1. In accordance with previous works (Maroušek 2012; Maroušek et al. 2012) it was confirmed that higher pressure does not mean linearly more intensive degradation of the phytomass. Increased

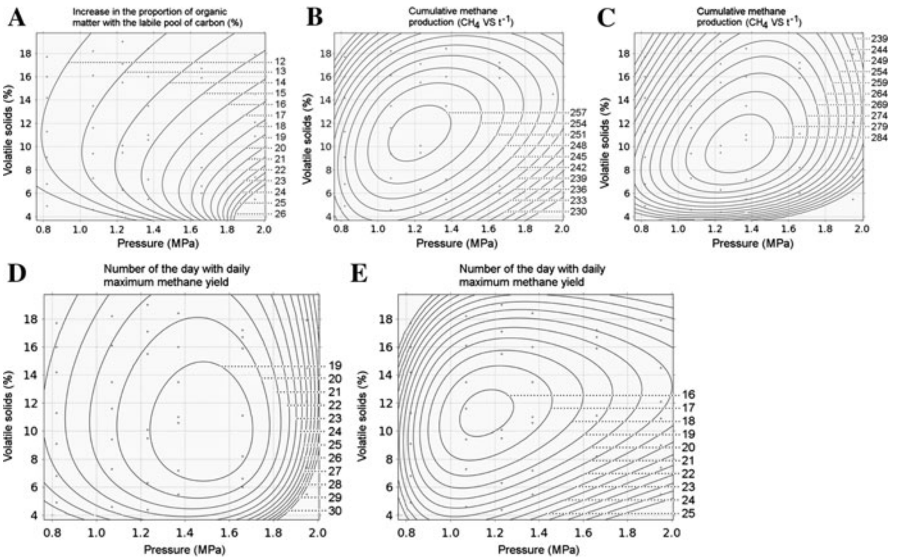

Fig. 3 **a** Manifestation of the steam explosion pretreatment measured as degradation of the organic components in response to high-pressure reactor operating pressure and VS. The *graph* shows that the increased pressure intensifies the pretreatment, however, the intensity is slowed by higher amounts of VS. **b**, **c** The plotted yields of cumulative methane production (m^3 VS t^{-1}, converted to 0 °C at 101,325 Pa) achieved from steam exploded substrate which was previously pelleted and macerated in hot water. *Graphs* shows that the optimal VS might be in the neighborhood of 11 % VS for both mesophilic (**b**) and thermophilic (**c**) conditions. Slightly higher pressure may be more appropriate for thermophilic (**c**) conditions, however, the farmer should be aware of the risk of inhibitor formations. **d** In case of mesophilic (40 °C) conditions the highest daily methane yields (m^3 VS t^{-1}, converted to 0 °C at 101,325 Pa) were earliest in the 19th day in the process of anaerobic fermentation. In case of thermophilic (50 °C) conditions (**e**) the highest yields could be observed a few days earlier which may be regarded as a consequence of economic importance while faster fermentation means smaller volumes of fermentors. The dynamics are plotted as a polynomial function; the sum of squared absolute error = 0.001 and the root mean squared error = 0.001

pressure intensifies the pretreatment, however, the intensity is slowed by higher amounts of volatile solids. In addition, results obtained from the subsequent mesophilic (40 °C) and thermophilic (50 °C) anaerobic fermentation shows, that more intensive degradation of organic components does not always mean higher methane yields (Fig. 3). The dissolved lignin due to, e.g., pretreatment of lignocelluloses is also an inhibitor for cellulase, xylanase, and glucosidase (Berlin et al. 2006), in addition, various cellulases differ in their inhibition by lignin, while the xylanases and glucosidase are less affected by lignin. The optimal VS may be in the neighborhood of 11 % for both mesophilic and thermophilic conditions. Slightly higher pressure might be more appropriate for thermophilic conditions, however, the farmer should be aware of the risk of inhibitor formations. In case of mesophilic conditions the highest daily methane yields (Fig. 3) were earliest in the 19th day. In case of thermophilic conditions the highest yields could be observed a few days earlier, which may be regarded as a consequence of economic importance while faster fermentation may be also interpreted as smaller volumes of fermentors. The methane yields achieved in optimal conditions were significantly higher than yields achieved without any pretreatment (Fig. 4). Ranali (2007) achieved 179–218 m^3 CH^4 VS t^{-1}. Uellendahl et al. (2008) state that 200 m^3 CH^4 VS t^{-1} was achieved from raw material, 360 m^3 CH^4 VS t^{-1} after wet oxidation. Klimiuk et al. (2010) state that methane productivity for *Miscanthus sacchariflorus* (0.19 ± 0.08 L g^{-1} VS) was twice that of *Miscanthus giganteus* (0.10 ± 0.03 L g^{-1} VS) and in accordance with our data add that the anaerobic fermentation run under mesophilic conditions needs longer retention times. It is assumed that the manifestation of the steam explosion pretreatment on the methane yields in the subsequent anaerobic fermentation is significant in both mesophilic (40 °C) and thermophilic (50 °C) conditions and methane yields slightly over 257 m^3 CH^4 VS t^{-1}, respectively 284 m^3 CH^4 VS t^{-1} may be achieved using the steam explosion technology. With regard to these key data it was figured out that the acquisition costs of the biogas station (3.4M EUR) are 16 times higher than the conventional combustion technology (Fig. 5). However, the profitability is almost double (11 % p.a. in

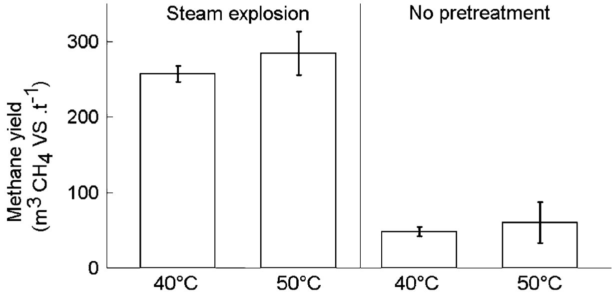

Fig. 4 It is assumed that the manifestation of the steam explosion pretreatment on the methane yields (m^3 CH_4 VS t^{-1}, converted to 0 °C at 101,325 Pa) in the subsequent anaerobic fermentation is significant in both mesophilic (40 °C) and thermophilic (50 °C) conditions. In addition the yields are much more variable at higher temperatures. The *bars* indicate standard deviations (n = 6, $\alpha = 0.05$)

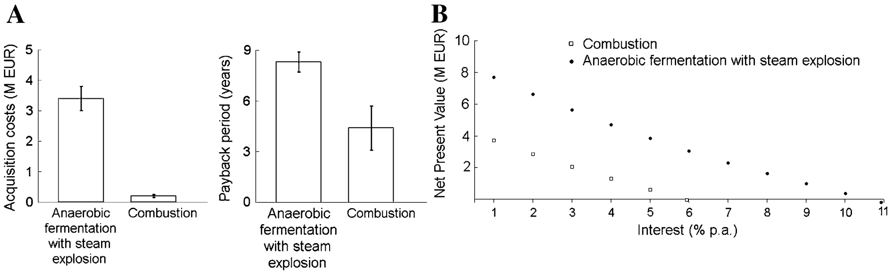

Fig. 5 **a** The technology of anaerobic fermentation with steam explosion is 16 times more demanding on acquisition costs and the payment period may be unfortunately up to two times longer than the conventional combustion. The *bars* indicate standard deviations given by practical experience. **b** Against all risks, the interest of anaerobic fermentation with steam explosion technology offers much higher interest than the conventional combustion technology (calculated from Net Present Value)

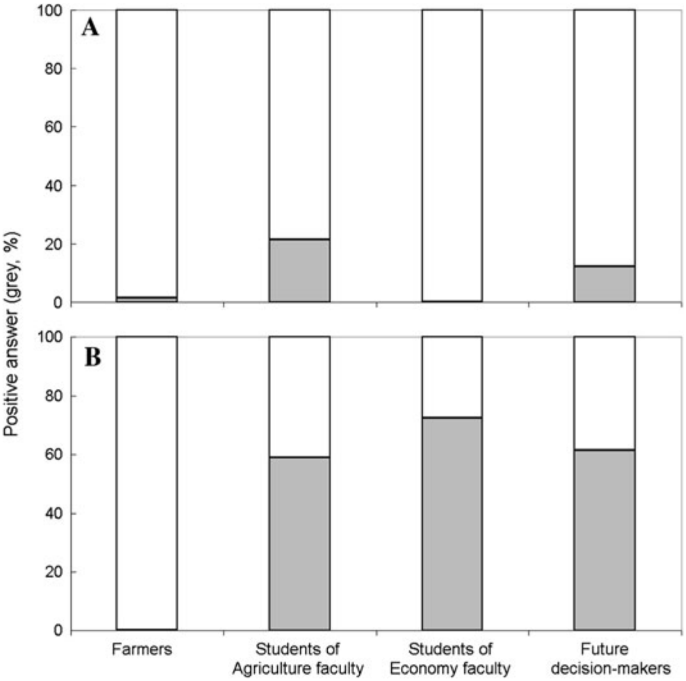

Fig. 6 **a** Are you aware of negative ecological impacts of phytomass combustion? **b** Would you prefer investment into anaerobic fermentation with steam explosion considering following environmental and economical data?

comparison to 6 % p.a.). Interesting situation may occur if the farmer already has biogas station and it is upgraded by the technology of steam explosion (Maroušek et al. 2012). Such an investment may result in remarkable shortage of the payback period. Closer look at statistical evaluation of the sample of nowadays decision-makers shows high correlation with unfavorable demographic data in annual Green Reports 1997–2010 of Ministry of Agriculture of Czech Republic underlining relatively high average age in Czech agriculture (more than 10 % farmers over 60 years, 45 % in the range of 45–59 years, less than 12 % under 29 years). Because the goal is to predict the future prevailing behavior of agriculture decision-makers in the next 2 decades, the fourth group, which included 2 youngest groups of farmers (therefore until the age of 44) and all the students was formed. The results (Fig. 6) shows that only the students of Agriculture faculty have some knowledge about the negative ecological impacts of phytomass combustion, probably because it's part of their education. The second key question on preference of more environmentally investment shows that the students tend to be more ethical and courageous than the nowadays decision makes. I hope they are likely to retain their ethical decision-making behavior and spread it in the population.

Conclusion

Hazards of phytomass combustion were confirmed. It can be assumed that the risks are higher in lower temperatures of combustion, for example in imperfect combustion conditions. The technology of steam explosion is indispensable from economical point of view, otherwise the anaerobic fermentation lasts disproportionately long or huge fermentors have to be build. The pretreatment of naturally hardly biodegradable phytomass (like *Miscanthus sinensis*) into easily fermentable substrate may be considered ethical only if it does not require any additional energy or chemicals farmer would not be able to produce from own sources. Utilization of the waste energy form the cogeneration unit combustion engine flue gases in a commercial scale proved that such solutions are possible. However, the pretreatment parameters of the steam explosion technology must be tailored to meet the biotechnological optimum while respecting the technology limitations and financial criteria. It was fount that the yields of the steam exploded substrate are more variable in thermophilic conditions. We state a hypothesis that this phenomena may be caused by inoculate specificity. The sample of current decision-makers in Czech agriculture were not interested in ethical values. However, the next generation of decision-makers is more interested in sustainability and ethical issues.

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