Sci Eng Ethics (2018) 24:299–305
https://doi.org/10.1007/s11948-017-9881-7

OPINION

Economic, Environmental and Moral Acceptance of Renewable Energy: A Case Study—The Agricultural Biogas Plant at Pěčín

Marek Vochozka[1] · **Anna Maroušková**[1] ·
Petr Šuleř[2]

Received: 1 December 2016 / Accepted: 24 January 2017 / Published online: 8 March 2017
© Springer Science+Business Media Dordrecht 2017

Abstract The production of renewable energy in agricultural biogas plants is being widely criticized because—among other things—most of the feedstock comes from purpose-grown crops like maize. These activities (generously subsidized in the Czech Republic) generate competitive pressure to other crops that are used for feeding or food production, worsening their affordability. Unique pretreatment technology that allows substitution of the purpose-grown crops by farming residues (such as husk or straw) was built 6 years ago on a commercial basis in Pěčín (Czech Republic) under modest funding and without publicity. The design of the concept; financial assessment and moral viewpoint were analyzed based on practical operating data. It showed that the apparatus improves economic, environmental and moral acceptance as well. However, according to the government's view, public funding for this type of processing was shortened, "because waste materials represent a lower cost". The impact of such governance was analyzed as well.

Keywords Environmental assessment · Moral consideration · Financial analysis · Process management · Renewable energy

Introduction

Increasing the share of renewable energy has been high on the policy agenda in many countries around the world over the past two decades (Wüstenhagen et al. 2007). Several governments have set ambitious targets and have started to realize

---

✉ Marek Vochozka
vochozka.marek@gmail.com

[1] School of Expertness and Valuation, The Institute of Technology and Businesses in České Budějovice, Okružní 517/10, 370 01 Ceske Budejovice, Czech Republic

[2] Faculty of Management and Informatics, University of Žilina, Univerzitná 8215/1, 010 26 Zilina, Slovak Republic

المنارة للاستشارات

support schemes aimed at facilitating market implementation. However, the literature on renewables has so far taken little notice of empirical research on public preferences carried out by environmental economists (Kolk 2016). Van der Horst (2007), stated that most of the negative impacts of renewable energy are mainly local in nature, such as noise or visibility in the location of residences. On the contrary, Pimentel (2003) claimed that so-called renewable energy has predominantly global impacts and that the energy balance, economics, and environmental impacts are negative. For instance, according to the same author, bioethanol production causes the degradation of the agricultural and natural environment and contributes to water pollution and air pollution. In comparison, Dale et al. (2014) recognized that sustainably deployed biofuels could contribute to solving challenging problems, including food and energy security, climate change and environmental degradation caused by current agricultural and forestry practices. This is in agreement with Maroušek et al. (2016) who noted that some of the pioneering renewable technologies are already price competitive and, moreover, capable of carbon sequestration making it possible to mitigate climate change. Meissner (2015) argues that the dominance of certain paradigms and theories on policies can have an influence on the value added by impact assessments, however, the ways in which politics are conducted in the Czech Republic resembles the paternalistic ruling of political parties over voters to a greater extent than any rational measures being taken (Hašková 2016). A generous subsidy system was announced by the government of the Czech Republic to support the construction of agricultural biogas plants that process purpose-grown crops (Mardoyan and Braun 2015). Initially similar measures are perceived by voters positively, but the consequences can be quite the opposite (Maroušek 2013). Social acceptance is a frequently used term in practical policy literature, but clear arguments as to its nature are rarely given (Wüstenhagen et al. 2007). According to Painuly (2001), the social, economic and environmental acceptance of renewable energy may vary across technologies and countries. Hašková (2016) recently confirmed that the improvement of existing technologies for renewable energy production is meeting with a better understanding of the public. The fact that such solutions are possible was also confirmed by Misra et al. (2016).

This paper focuses on the techno-economic identification of the moral aspects in the agricultural biogas business and interactions regarding its techno-economical improvement. Subjecting phytomass to high temperature and pressurized live steam that is suddenly released makes its inner lignocellulose structures partly collapse due to the sudden change in pressure (Maroušek 2012). This process is called steam-explosion (SE) and the first observations of it date back to the second half of the nineteenth century. The initial SE devices and processing parameters were designed to loosen sawdust so as to be able to form particleboards. Nowadays, this process is being rediscovered, to lower the natural resistance of phytomass to the subsequent biodegrading processes, which allows the production of biofuels and various chemicals as well. The SE pretreatment effect is achieved by a complex of cavitation forces during the quick pressure drop as the phytomass is quickly released from the steam-pressurized reactor back to the atmospheric pressure. These forces disintegrate the rigid lignocellulose structures and liberate the labile organic matter.

للاستشارات

The natural resistance of the native plant matter is partly broken and any bioprocessing techniques are thus made easier. However, Chen and Liu (2015) reviewed that the sporadic efficiency of the pretreatment and the lack of basic theory are the main challenges to its industrial implementation. For that reason many attempts have been made to intensify the pretreatment effect by using different hydrolyzing agents (acid; alkali or enzymatic). When reaching the SE process temperatures (usually in the range of 160–240 °C; respectively 0.8 up to 1.6 MPa), the hydrolyzing efficiency of acids and alkalis is also increased (Yang et al. 2013). Acids like H_2SO_4 and HCl are used most often (Wijaya et al. 2014). Regarding alkali, NaOH and KOH have been tested the most (Bjerre et al. 1996). The processing parameters of SE are too severe to make it possible to use the hydrolyzing effect of enzymes. Enzymatic hydrolysis can be carried out subsequently in separate reactors for considerably longer times (usually in the range of 10 up to 100 h) at lower temperatures (usually 40–65 °C) and on a lignocellulose that was already previously pretreated by SE (Maroušek et al. 2013). Various combinations of the above stated techniques can be traced in the literature (Kumar et al. 2009). Alternatives where the steam is replaced by supercritical NH_3 (Sun and Cheng 2002) or CO_2 (Kim and Hong 2001) were also reported.

What all these additional hydrolyzing applications have in common are not only the high construction costs of the plant and equipment, but also the significant energy demands and all the issues related to the management of hydrolyzing reactants (Maroušek et al. 2012). These are not only costly themselves, but also increase the running cost because of corrosion and other safety measures. To make matters worse, substances formed during the pretreatment of the lignocellulosic feedstock may inhibit enzymatic hydrolysis, as well as the subsequent microbial fermentation steps (Jönsson et al. 2013).

Commercial deployment acidic or alkaline hydrolysis is financially unsustainable (Maroušek et al. 2014). Most of the SE apparatus mentioned in the literature are designed for batch experimental purposes (McIntosh et al. 2016). Presumably due to energy demands, it cannot be found that any other than the one mentioned in this study (Pěčín, Czech Republic) operated on a commercial scale (Cotana et al. 2014). In response to the above stated energy demands, it was proposed to integrate the SE pretreatment unit into the complex of a biogas plant so that it was not necessary to provide running energy for its operation from costly external sources. It was stated in the hypothesis whether such a solution is viable from a techno-economical standpoint in the long term and whether (or how) could the perception of renewable energy be changed thereby. The following events develop the hypothesis of whether it is reasonable to penalize the processing of waste residues in comparison to generously donated energy production from purpose-grown crops.

Methods

Biogas station Pěčín (Czech Republic) is equipped with the JMS 416 cogeneration unit (GE Jenbacher, Germany) that provides electrical power of 564 kW and thermal output of 706 kW. The anaerobic fermentation runs continuously at 37 °C; 8 k h year^{-1}. The

المنارة للاستشارات

feedstock originally consisted of on-farm purpose-grown maize silage; grass silage and swine slurry that were mixed to obtain volatile solids (VS) of 15% to make stirring cost-effective. Neglecting small qualitative variations, if the data of maize silage from harvests of 2011–2016 (5 kt year^{-1}) were converted to 30% VS and the currency changes during these years converted to EUR of 15th October 2016 it can be stated that the internal cost is 35.4 ± 3.2 EUR t^{-1}. Maize silage (converted to 30% VS) itself provides electricity production of 338.5 ± 32.7 kWh t^{-1}. If the grass silage (6 kt year^{-1}) is converted to 25% VS, the internal cost is 31.7 ± 4.0 EUR.t^{-1}, which provides 211.3 ± 18.4 kWh t^{-1}. The internal costs of swine slurry (3% VS; 6.57 kt year^{-1}) are estimated to be negligible because of the waste nature of the feedstock and also because its fertilization value is equivalent to the cost of its management. Use of swine slurry in the biogas plant resulted in 34.7 ± 15.8 kWh t^{-1} (3%VS). The mixture of the untreated feedstock all together provided 312.7 ± 15.0 kWh t^{-1} with biogas purity of $52.4 \pm 3.0\%$ CH_4. Incorporation of the SE technology (acquisition costs 0.7 M EUR, schema of the incorporation outlined in Fig. 1) changed the feedstock and energy management. An important innovation was the recuperation of waste heat (thermal output of 706 kW) from the JMS 416 biogas cogeneration unit. It became clear that this energy is satisfactory enough to create a sufficient amount of 210 °C live hot steam to run the whole SE technology and also the under-hot-water macerator M2 (Aivotec, s.r.o., Czech Republic). The M2 operates at 85 °C; with a hydraulic retention time of 200 s and it has replaced the original feedstock feeder to prevent subsequent pressure variations in the high-pressure reactor (BiomassTechnology, s.r.o., Czech Republic). The (operating at 1.2 MPa; hydraulic retention time 10 min) ended with the sudden expansion of the mash into a low pressure vessel where the SE took place. The expanded low pressure phytomass mash was mixed with the swine slurry and pumped into the battery of 3 serially interlinked temperature controlled (37 °C) and slowly stirred anaerobic fermentors in which the

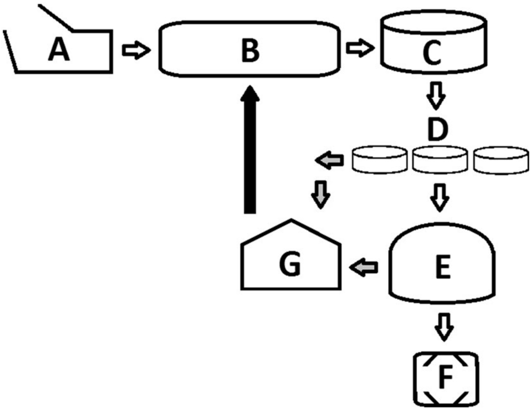

Fig. 1 Schema of the material (*arrows filled white*) and energy flows, where *A* feedstock feeder, *B* continuous steam-explosion pretreatment unit; *C* mixer; *D* battery of tempered and slowly stirred anaerobic fermentors; *E* final fermentor with biogas storage; *F* separator for dewatering of the fermentation residues; *G* biogas (*arrows filled gray*) combustion engine that produces electricity (not illustrated) as well as significant amount of waste heat (*long black arrow going upwards*) that is used to run the *B*

المنارة للاستشارات

biogas generation took place. The biogas (53.1 ± 2.9% CH_4) was collected for the combustion engine. Following this upgrade, the manifestations of the methanogenesis changed as follows. SE pretreated maize silage provides 418.5 ± 39.0 kWh t^{-1}; grass silage 287.2 ± 33.9 kWh t^{-1}. However, taking into account the lifetime (20 years) and corresponding running cost of the SE apparatus, the internal feedstock cost rose to 39.0 ± 2.1, 36.5 ± 1.3 EUR t^{-1} respectively. The swine slurry is still used for its inoculation abilities and therefore is not subjected to the SE pretreatment. However, the biogas station is subsequently able to process straw (internal cost 30.2 ± 2.2 EUR t^{-1}, converted to 90% VS) at 174.5 ± 42.1 kWh t^{-1}. The purchasing price of electricity from biogas stations that process purpose-grown phytomass is 152.6 EUR MWh^{-1}, the purchasing price on electricity from waste phytomass is limited to 131.5 EUR MWh^{-1}.

Results and Discussion

Social acceptance as a part of renewable energy technology implementation has largely been neglected when the relevant policy programs started (Wüstenhagen et al. 2007). It was repeatedly shown (Maroušek et al. 2015) that neither public support, nor support from crucial stakeholders at varying levels could be taken for granted. Environmental economists speak of the total economic value (TEV) of an organism, habitat or landscape (or any mix of these found in a certain location) as the sum of all market and non-market values (Van der Horst 2007). Therefore, it is necessary to assess them from both the moral and financial point of view, because they can hardly be fully separated (Hašková 2016). Regarding maize silage, our findings revealed that the technological innovation (incorporation of the SE process) resulted in increased energy yields of 23.6%. This can be interpreted as a reduction in maize sowing by almost a quarter. It can therefore be argued that the TEV of the area was improved because there was an increase in plant species diversity and the interlinked water management of the soil. Concerning grass, the yields have improved by 35.9%, which can be explained by feedstock saving of more than a third and an analogous TEV increase. Additional savings in feedstock and improvement of the TEV in surrounding cultivated areas can be achieved by the use of straw. However, practical experience has shown that it is reasonable to replace only half of all the feedstock by the SE pretreated straw. At higher doses, it would be necessary to make additional equipment modifications, since the process began to be less stable, which was reflected, for example, in higher variability (52.3 ± 6.4% CH_4) of biogas quality (compared to the fermentation of raw phytomass 52.4 ± 3.0 CH_4 and SE pretreated feedstock without the addition of SE pretreated straw 53.1 ± 2.9 CH_4). Thus, a significant increase in CH_4 variance impacted the efficiency of the cogeneration unit and the amount of electricity sold to the public network. However, following the findings of Kolář et al. (2008) the inaccuracies of the calculations related to the processing of straw because the waste straw from this process is less effective in rendering the soil more productive (Maroušek 2014). Regardless, better performance due to the incorporation of the SE pretreatment is balanced by its cost and limited purchasing price of electricity, therefore the payback period remains within the range of 6–7 years. Pimentel (2003)

المنارة للاستشارات

claims that increasing the cost of food and diverting human food resources to the costly, inefficient production of renewable fuel raises major ethical questions. A subsequent analysis of Ajanovic (2011) on whether the production of renewables increases food prices does not give a clear answer. Analyzing data from a different perspective showed that it is possible to save approximately 2 kt year^{-1} of maize silage and the same amount of grass silage. In regard to all these above stated positive arguments, the penalization for processing of waste biomass that is hard to justify.

Conclusions

The findings obtained in this case study lead to the conclusion that reasonable technological advances and process management in farm biogas stations might improve the versability of renewable energy. SE causes significant changes in phytomass biodegradability whence the energy recovery of waste heat and subsequent overall betterment of the material and energy flows boosts the overall process efficiency. Feedstock inputs of purpose-grown phytomass were reduced and accordingly the pressure on food prices decreased. Thereby environmental acceptance is improved because it is possible to reduce the range of the technology and the impact on the local environment. Accurate quantification was not needed to confirm that the TEV of the surrounding arable land increased due to improved plant species diversity and the interlinked water management of the soil. Analysis of the operating data revealed that incorporation of the technological improvements undoubtedly increases the acquisition cost, however, the payback period is not prolonged significantly, because the energy consumption, storage and handling costs themselves are reduced whereas biogas yields increase.

References

Ajanovic, A. (2011). Biofuels versus food production: Does biofuels production increase food prices? *Energy, 36*(4), 2070–2076.

Bjerre, A. B., Olesen, A. B., Fernqvist, T., Plöger, A., & Schmidt, A. S. (1996). Pretreatment of wheat straw using combined wet oxidation and alkaline hydrolysis resulting in convertible cellulose and hemicellulose. *Biotechnology and Bioengineering, 49*(5), 568–577.

Chen, H. Z., & Liu, Z. H. (2015). Steam explosion and its combinatorial pretreatment refining technology of plant biomass to bio-based products. *Biotechnology Journal, 10*(6), 866–885.

Cotana, F., Cavalaglio, G., Gelosia, M., Nicolini, A., Coccia, V., & Petrozzi, A. (2014). Production of bioethanol in a second generation prototype from pine wood chips. *Energy Procedia, 45,* 42–51.

Dale, B. E., Anderson, J. E., Brown, R. C., Csonka, S., Dale, V. H., Herwick, G., et al. (2014). Take a closer look: Biofuels can support environmental, economic and social goals. *Environmental Science and Technology, 48*(13), 7200–7203.

Hašková, S. (2016). Holistic assessment and ethical disputation on a new trend in solid biofuels. *Science and Engineering Ethics*. doi:10.1007/s11948-016-9790-1.

Jönsson, L. J., Alriksson, B., & Nilvebrant, N. O. (2013). Bioconversion of lignocellulose: Inhibitors and detoxification. *Biotechnology for Biofuels*. doi:10.1186/1754-6834-6-16.

المنارة للاستشارات

Kim, K. H., & Hong, J. (2001). Supercritical CO_2 pretreatment of lignocellulose enhances enzymatic cellulose hydrolysis. *Bioresource Technology, 77*(2), 139–144.

Kolář, L., Kužel, S., Peterka, J., Štindl, P., & Plát, V. (2008). Agrochemical value of organic matter of fermenter wastes in biogas production. *Plant, Soil and Environment, 54*(8), 321–328.

Kolk, A. (2016). The social responsibility of international business: From ethics and the environment to CSR and sustainable development. *Journal of World Business, 51*(1), 23–34.

Kumar, P., Barrett, D. M., Delwiche, M. J., & Stroeve, P. (2009). Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. *Industrial and Engineering Chemistry Research, 48*(8), 3713–3729.

Mardoyan, A., & Braun, P. (2015). Analysis of Czech subsidies for solid biofuels. *International Journal of Green Energy, 12*(4), 405–408.

Maroušek, J. (2012). Finding the optimal parameters for the steam explosion process of hay. *Revista Técnica de la Facultad de Ingeniería, 35*(2), 170–178.

Maroušek, J. (2013). Study on agriculture decision-makers behavior on sustainable energy utilization. *Journal of Agricultural and Environmental Ethics, 26*(3), 679–689.

Maroušek, J. (2014). Significant breakthrough in biochar cost reduction. *Clean Technologies and Environmental Policy, 16*(8), 1821–1825.

Maroušek, J., Hašková, S., Zeman, R., Váchal, J., & Vaníčková, R. (2014). Nutrient management in processing of steam—exploded lignocellulose phytomass. *Chemical Engineering and Technology, 37*(11), 1945–1948.

Maroušek, J., Hašková, S., Zeman, R., Váchal, J., & Vaníčková, R. (2015). Assessing the implications of EU subsidy policy on renewable energy in Czech Republic. *Clean Technologies and Environmental Policy, 17*(2), 549–554.

Maroušek, J., Itoh, S., Higa, O., Kondo, Y., Ueno, M., Suwa, R., et al. (2013). Enzymatic hydrolysis enhanced by pressure shockwaves opening new possibilities in *Jatropha curcas* L. processing. *Journal of Chemical Technology and Biotechnology, 88*(9), 1650–1653.

Maroušek, J., Kawamitsu, Y., Ueno, M., Kondo, Y., & Kolář, L. (2012). Methods for improving methane yield from rye straw. *Applied Engineering in Agriculture, 28*(5), 747–755.

Maroušek, J., Vochozka, M., Plachý, J., & Žák, J. (2016). Glory and misery of biochar. *Clean Technologies and Environmental Policy*. doi:10.1007/s10098-016-1284-y.

McIntosh, S., Zhang, Z., Palmer, J., Wong, H. H., Doherty, W. O., & Vancov, T. (2016). Pilot-scale cellulosic ethanol production using eucalyptus biomass pre-treated by dilute acid and steam explosion. *Biofuels, Bioproducts and Biorefining, 10*(4), 346–358.

Meissner, R. (2015). The relevance of social theory in the practice of environmental management. *Science and Engineering Ethics, 22*(5), 1345–1360.

Misra, N., Panda, P. K., Parida, B. K., & Mishra, B. K. (2016). Way forward to achieve sustainable and cost-effective biofuel production from microalgae: A review. *International Journal of Environmental Science and Technology, 13*(11), 2735–2756.

Painuly, J. P. (2001). Barriers to renewable energy penetration: A framework for analysis. *Renewable Energy, 24*(1), 73–89.

Pimentel, D. (2003). Ethanol fuels: Energy balance, economics, and environmental impacts are negative. *Natural Resources Research, 12*(2), 127–134.

Sun, Y., & Cheng, J. (2002). Hydrolysis of lignocellulosic materials for ethanol production: A review. *Bioresource technology, 83*(1), 1–11.

Van der Horst, D. (2007). NIMBY or not? Exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies. *Energy policy, 35*(5), 2705–2714.

Wijaya, Y. P., Putra, R. D. D., Widyaya, V. T., Ha, J. M., Suh, D. J., & Kim, C. S. (2014). Comparative study on two-step concentrated acid hydrolysis for the extraction of sugars from lignocellulosic biomass. *Bioresource Technology, 164,* 221–231.

Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy policy, 35*(5), 2683–2691.

Yang, Z., Kang, H., Guo, Y., Zhuang, G., Bai, Z., Zhang, H., et al. (2013). Dilute-acid conversion of cotton straw to sugars and levulinic acid via 2-stage hydrolysis. *Industrial Crops and Products, 46,* 205–209.

المنارة للاستشارات

Science & Engineering Ethics is a copyright of Springer, 2018. All Rights Reserved.

www.manaraa.com