MARGINAL EFFECTS OF BIOGAS PRODUCTION ON ENVIRONMENTAL, WASTE AND AGRICULTURE POLICY

Biljana Kulisic
Energy Institute Hrvoje Požar, Department for Renewable Energy Sources and Energy Efficiency
Savska 163, HR-10000 Zagreb, Croatia; phone: +385/1-6326169; fax: +385/1-6040599; e-mail: bkulisic@eihp.hr

William White
Natural Resources Canada, Canadian Forest Service, Northern Forestry Centre
5320 122nd St. Edmonton, AB Canada T6K 3M6; phone: 780-435-7315; fax 780-435-7359; email: bwhite@nrcan.gc.ca

ABSTRACT: Biogas, a renewable energy source, provides numerous socio-economic benefits from GHG emissions reduction, soil improvement, waste reduction to new economic activity that will diversify rural economies and provide new employment opportunities. Nevertheless, it is often forgotten that establishing an agricultural biogas plant is an investment intensive venture with a long pay back period. The purpose of this work is to provide a methodology for local and national decision makers to assist in nowing whether and when supporting biogas project is justified social cost.
Keywords: biogas, marginal effects, policy

1 INTRODUCTION

Biogas production and utilisation could bring numerous benefits which have been recognised, directly or indirectly, in 15 EU Directives and several related regulations that originate from the energy, environmental protection, waste and agriculture sectors. On the other hand, scientific and expert research has been focused on individual aspects of anaerobic digestion aimed at microbiology, energy recovery, technical issues, feedstock, GHG reduction …from the point of view various scientific fields [1], [2], [3], [4].

Throughout the paper, cross-cutting sector analyses combined with results of scientific research on different aspects of biogas production are discussed to facilitate policy development towards support of biogas. The paper is structured as follows: the first section briefly reflects on biogas production and utilisation and identifies externalities which form a biogas bundle of products or market and nonmarket cobenefits [5]. The next section identifies vertical biogas market players, their drivers and assigned roles that are going to be matched with biogas benefits (section three). It is followed by suggesting guidelines for shaping an integrated biogas policy involving national and regional level market players. Concluding remarks complete the paper

2 BIOGAS – A BUNDLE OF PRODUCTS

Although considered as a type of renewable energy source (RES), biogas always comes as a bundle of products to the society as a whole. Not only does it provide useful energy, it saves GHG emissions via the substitution effect by replacing fossil fuels and from utilising methane that would have otherwise been emitted into the atmosphere through the decomposition of organic matter. Agricultural biogas plants represent the most complex layout for generation of renewable energy. Biogas produced from agricultural feedstock affects RES targets, Kyoto targets, agricultural practice and socio-economic issues of a rural community.

A biogas product bundle participates in several markets which have been recognised in approximately 15 EU Directives and Regulations [6]. Transposition of those directives to national legislation entails a new set of legal documents that makes biogas either a legally complicated issue (administrative permit approval) or if the project does not go forward, society loses the opportunity to obtain the benefits from biogas.

From the demand side, agricultural biogas plants are competing in agricultural markets for feedstock, either for manure, land or at the feed market. On the supply side, biogas first competes in all energy markets – electricity, heat, fuel or gas. Leftover from anaerobic digestion – digestate, competes in fertiliser markets if only manure and energy crops are included as feedstock. From the supply side, biogas plants also participate in the GHG market. Biogas diversifies rural economies which include biogas production among measures for promoting rural development.

Assuming that renewable energy is the core purpose for biogas production, one should evaluate each product of a bundle in order to assess the marginal effects of biogas production on environmental, waste and agriculture policy.

2.1 Renewable energy production

Renewable energy legislation describes biogas most comprehensively. Biogas is included among RES and represents a convenient primary energy source that can be converted in different useful energy forms. Average size of biogas plants in the EU is 300 kW which is, in comparison to the other installed capacities for RES-E generation, relatively small (1). Nevertheless, biogas contributed with 5.9 Mtoe of primary energy and 19 937 MWh of gross electricity production in the EU in 2007 with Germany leading the way [7]. 36% of primary energy from biogas or 2 108 Mtoe originated from “other sources than landfill and waste water treatment plants”, which are mainly agriculture type of biogas plants (centralised and decentralised mono- and co-digestion biogas units).

In view of renewable energy production, energy is usually produced in anaerobic digestion process (AD) or controlled decomposing of organic matter without the presence of air where the final product is biogas. Biogas is a mixture of gases, major and disproportional share of CO_2 and CH_4, <0.05 of H_2S, <0.05 of NO_x and 1-2% of water vapours. The energy value of biogas is related to the share of methane in the gas mixture. Such biogas could be utilised in cogeneration plants for electricity and heat or further purified and upgraded to obtain pure methane or characteristics equivalent to those of natural gas.

Sources of AD feedstock can be found in the agro-food industry either as by-products, waste or as a dedicated energy crop. Different feedstock has different energy content and digestion characteristics. Biogas production is a mature technology with predictable characteristics [8] and output. Biogas yield depends on the total dry matter and volatile solids share in the dry matter. Once the process of AD has been established, minimum changes in feedstock composition are allowed. Agricultural biogas plants are operating mostly on livestock manure mixed with organic (cereal, silage) plant material with higher energy value.

Manure is considered as the most basic AD feedstock. It contains favourable features for AD (anaerobic cultures of methanogenic bacteria, high water content (4-10% dry matter, solvability…) [9]. In addition, manure is a by-product which makes it an affordable feedstock available over the whole year. Designing an agricultural biogas plant is a challenging venture as each location will have its own peculiarities. Quantity and quality of livestock manure depends upon numerous factors (type and breed of animal, weight, age, nutrition, purpose of breeding…) while biogas yield further depends on the "purity" of substrate (bedding and its types, mixture and ratio of urine and manure, farm management, presence of antibiotics and disinfection agents that disturb generation of methane…) [9], [10]. For that reason, energy potential from animal excrement will vary from farm to farm, even if the same type and number of animals are present. Recent mushrooming of AD plants, mainly on maize silage, is related to the desirable homogeneity of such feedstock that stabilises the AD process and provides stable and high biogas yields. The large majority of agricultural biogas plants employ co-digestions. Adding organic matter of higher energy content to animal excrement either increases biogas yield per unit of substrate or the share of methane in biogas increases or both. Results of co-digestion are, in general, higher than the sum of substrates used in co-digestion digested separately [10]. That fact leads combinations and biogas yields from co-digestions towards infinity. Cogenerations are, in practice, calculated for micro-locations only. This paper will investigate monodigestions running on livestock manure and average parameters as it is not our aim to assess biogas plant from the investors' point of view but to the society (country, region) as a whole.

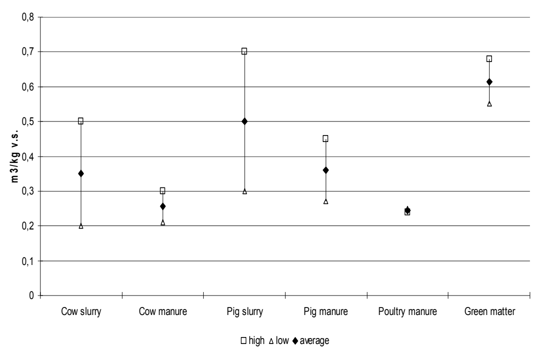

Figure 1 Biogas generation according to the livestock manure [11]

2.2 GHG emissions savings

The quantity of GHG savings from biogas will depend, firstly, on the feedstock used for biogas production and, secondly, on the energy produced to replace the usual energy of fossil origin.

GHG savings from utilisation of livestock manure as feedstock for biogas production are related to IPCC methodology of manure management, excluding emissions from enteric fermentation [12]. Utilisation of dairy cow manure as biogas production feedstock provides the largest potential in GHG savings whereas the same effect can only be achieved by 50% more bulls, calves or pigs; 60 times sheep or goats and 500 times more poultry (Table 1, [12]).

Table I: Comparison of biogas GHG emissions savings benefit from different types of livestock for kgCO2eq/yr

Animal type	number of animals
Dairy cows	1
Calves	1.5
Pigs	1.5
Sheep	60
Poultry	500

GHG savings from replacing fossil fuel with a renewable energy source will depend on the type of useful energy generated from biogas and the matching substitution effect. Useful energy forms originated from biogas can be electricity, heat and motor vehicle fuel. If purified and upgraded, biogas (methane) could be a true substitute to natural gas. According to the EU documents [8], direct (stack) emissions from biogas are equivalent to 5 kg CO2/MWh of electricity generated while lifecycle GHG emissions (including building the plant, transportation costs, etc.) equal 245 kg CO2/MWh.

Figure 2 presents possible GHG savings from substitution effect of having electricity generated from biogas instead of different fossil fuels types (less stack and lifecycle emissions from biogas). Countries with a high share of coal fired power plants would be highly motivated to find energy sources with possibilities of GHG neutral or savings characteristics before carbon capture and storage (CCS) technology becomes commercial. Biogas still represents more favourable option than coal with CCS even when comparing by lifecycle emissions.

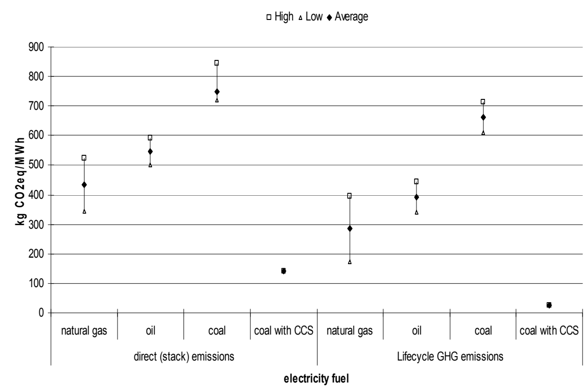

Figure 2 CO2eq emissions savings from different substitution effects of fossil fuels for electricity generation (direct and lifecycle GHG emissions)

Figure 3 presents possible GHG savings from utilising biogas for heat and motor vehicle fuel excluding direct (stack) emissions from biogas. It is assumed that heat will originate from cogeneration plant where CO2eq emissions have been attached to the electricity generation. One cubic meter of biogas contains approximately 0.05 toe, while a cubic meter of purified and upgraded biogas would be perfect substitute for natural gas.

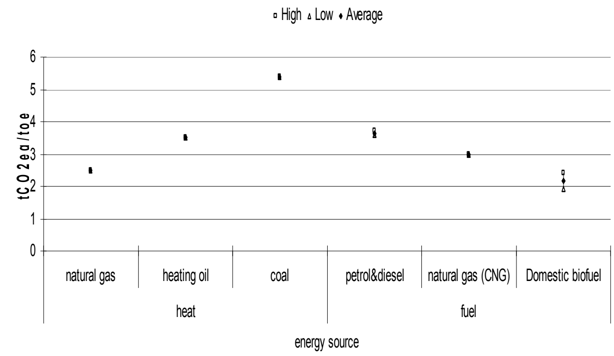

Figure 3 CO2eq emissions savings from different substitution effects of fossil fuels for heat production or motor vehicle fuel consumption

2.3 Land use

Land use is the most controversial in the bundle of biogas benefits as its quality is strongly correlated with regional and local conditions. Most research has been focused on nutrition value of digestate and its advantages in application as organic fertiliser over mineral fertilisers or the application of fresh manure. This holds true as biogas has been recognised as one of the main measures of good agriculture practice in manure management, popularly named Nitrate Directive [13]. The Nitrate Directive allows 170 kg N/ha per year and the application of manure at only certain times of the year and in certain areas in order to protect surface and underground water and to keep the nutrition values of arable land. This quality of biogas production to remove excess nitrogen from land and produce organic fertiliser as a by-product is especially emphasised in areas with intensive livestock production.

Biogas production is most likely to occur in rural economies, close to the feedstock source, either livestock breeding (manure) or/and arable land (energy crops). In practice, monodigestions are rather rare while most biogas production relies on a combination of two or more different feedstock. Among co-digestions, a combination of animal manure as base and energy crops (dominantly maize silage) to increase biogas yields is emerging as the most favourable combination. For a 500 kW biogas plant, there should be approximately. 200 ha/yr available for growing of maize. Including the minimum crop rotation regime, this increases demand for arable land to 600 ha. In addition, efficient livestock farming usually combines livestock breeding with feed growing. Generally speaking, farmers are relating 2-3 LU (2) (less efficient agriculture) and 3-5 LU (developed agriculture) with one hectare of arable land. In this case, land use could be both positive and negative part of biogas bundle, depending on the availability of arable land and whether that land is leased or in permanent ownership.

2.4 Socio-economic issues

Biogas production will occur only if an investor perceives it as an economically feasible venture. Electricity produced from biogas has been recognised in RES-E related legislation where the investor gains a special, higher price for sales of electricity to the grid. The profitability of a biogas plant will be also highly influenced if sufficient feedstock is available inreliable, affordable and appropriate quantities. An investor is more likely to recognise biogas as a business opportunity in countries with dominantly intensive livestock farming than countries with fragmented agricultural land and a small number of animals per animal husbandry or livestock farm.

Biogas operators earn revenue from sales of energy from biogas and sales of organic fertiliser. The cost side will be represented, apart of investment costs, by the feedstock price, transportation costs, operating and maintenance costs. A biogas plant is an intensive investment venture with, investment costs varying from 2 960 to 5 790 €2005/kW (average 3 190 €2005/kW) and annualised operation and maintenance costs (variable and fixed costs) are from 237 to 374 €2005/kW (average 245 €2005/kW) [8].

A community's entrepreneurship in general will strongly depend on the demographics of the rural community such as age, level of education in investment intensive ventures, as well as in the perception of biogas plants by the general public.

3 BIOGAS MARKET PLAYERS

Different players of a bioenergy market have different drivers that shape their actions within their given role [14]. Attributing identified benefits from biogas production and utilisation to the corresponding biogas market player, one could relate their distribution amonga vertical or hierarchy line.

The starting point or nucleus of biogas production is the private investor whose main driver is profit. An additional driver is the ease of accomplishing that investment.

Energy policy, in terms of energy supply, security, affordability and availability, is a driver of a national government and designated body (MoE (3)). Among other actions taken for implementing energy policy, a mandated renewable energy share in the total energy consumption is set in the EU countries and beyond. The driver of MoE to reach the mandated share is overlapping with the driver of biogas investor since both are better off in case when a biogas plant produces optimal yields. This overlapping of drivers has been recognised in RES-E legislation (feed-in tariff, quota system) or other support mechanisms – either financial (i.e. soft loans) or administrative (i.e. one stop shop).

Kyoto Protocol targets are set at the national level which means that MoGHG (4) will recognise GHG emissions savings as a driver among the biogas benefits bundle. The part of GHG savings from substitution effect by replacing fossil by non-fossil energy has already been embedded in contemporary energy policies [15],[16] whereas GHG emissions from manure management are described in IPCC guidelines [12] without specifically addressing biogas plants.

MoA (5) will be interested in farmers' welfare which is related to implementation of best agricultural practice and land use. A regional government aims to develop its regional economy and improve the standard of living of its inhabitants. Its driver would be diversification of rural economy with biogas. The standard of living could be improved by having energy from local sources (energy security) and removing odours. A spatial planning office should recognise land use as its main driver. By employing its resources – agricultural land for biogas production in a sustainable way – it facilitates diversification of the economy and creates job opportunities. Whereas excess livestock manure could be used by producing biogas, and thus, the Nitrate directive becomes implemented and the standard of living and the living environment of the community is increased.

4 MATCHING BIOGAS BUNDLE WITH MARKET PLAYERS

The effects of biogas production and its utilisation within energy policy have been established in the previous sections. The quality of a biogas bundle will vary according to the feedstock used for biogas production. The marginal effects from biogas bundle to other sectors will be demonstrated on a hypothetical, average sized monodigestion biogas plant (300 kW, η=31%, 7 700 working hours, 60% share of methane in biogas, investment 957 000 €2005).

Electricity production from this hypothetical biogas plant would save 1 005, 1 259 or 1 733 tCO2eq/year due to the substitution effect to the power plant fuelled by natural gas, oil or coal, respectively.

The Figure below indicates the approximate number of animals needed to produce feedstock for the same amount of electricity. Biogas yields vary not only by type of animal but also among the same type of animal (Figure 1). Parameters for calculating biogas yields are taken from [17] and converted to average values in this article for demonstration purposes. Investigated groups of animals are: cattle (young cattle between 1 and 2 years (high), dairy cows (low) and feeder cattle, cows (average)), pigs (young pigs heavier than 20 kg (high), sows (low) and feeder pigs (average)) and poultry (young hens with less than 0.8 kg weight (high), laying hens (low) and young hens or feeder poultry with less than 1.2 kg of weight (average)). Figure 4 pinpoints an important conclusion: the order of magnitude in number of heads/beaks, needed for production of the same energy amount, increases by 10 from cattle (1 000) to pigs (10 000) and by 100 from cattle (1 000) to poultry (100 000).

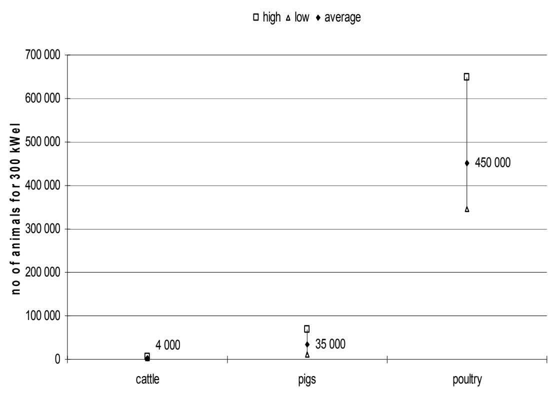

Figure 4 Approximate numbers of animals needed for supplying feedstock for 300 kW biogas plant

For the same amount of energy produced from biogas, Figure 5 attributes GHG emission savings from manure management using default values for moderate climate area from IPCC guidelines. It can be seen that MoGHG would favour most biogas plants running on pig manure as their savings are of a higher order of magnitude by 10 than CO2eq emissions from either cattle or poultry. A 300 kW biogas plant could save up to 6 000 t CO2eq/yr from utilising manure from farms with young pigs heavier than 20 kg.

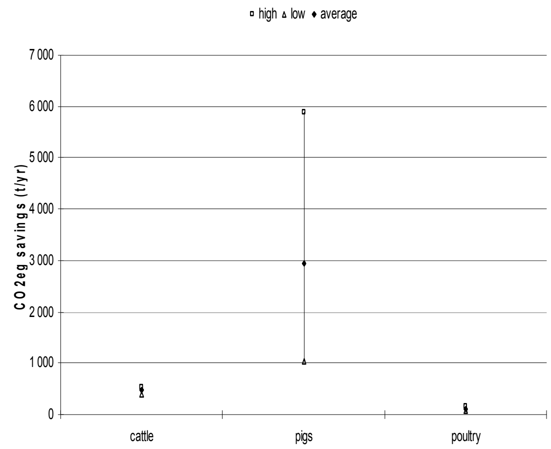

Figure 5 Approximate GHG emissions from manure management saved due to the production of the same amount of energy from biogas

In respect to the Nitrate Directive, arable land will be disburden the most if pig manure is utilised for biogas generation (~2 000 ha) but closely followed by cattle (~1 500 ha). Poultry manure is almost fourfold richer in gas production than those of cattle and pigs which, together with their light weight, results in ~ 500 ha of land relieved from nitrates. As each country has its own peculiarities when transposing the Nitrate Directive to its national framework, the values are taken from Croatian equivalent to Nitrate Directive [18] where: 70 kgN/ha per LU of cattle, 80 kgN/ha per LU of pig and 85 kgN/ha per LU of poultry or 2.428 LU of cattle/ha, 2.125 LU of pigs/ha and 2 LU of poultry/ha in order to meet 170 kgN/ha per year.

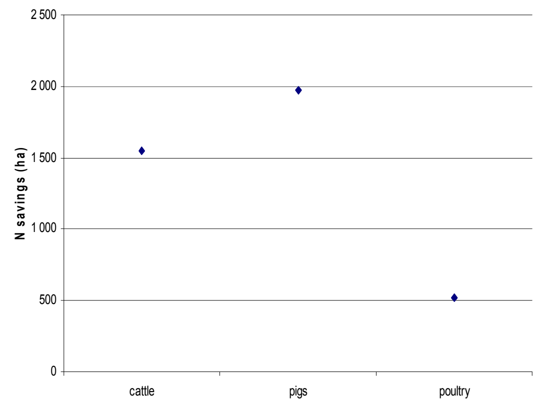

Figure 6 Disburden area (ha) of agricultural land from the same amount of energy produced from biogas

Using land for growing energy crops is not by default a negative issue as it depends on land availability. If one wants to build an additional biogas plant running on energy crops, next to the hypothetical one, maximal available area energy crops would be: total arable land – land needed for animals supplying the existing plant (Figure 7). The assumption is 3 LU/ha which is the higher margin for countries with less developed agriculture and lower margin for countries with developed agriculture.

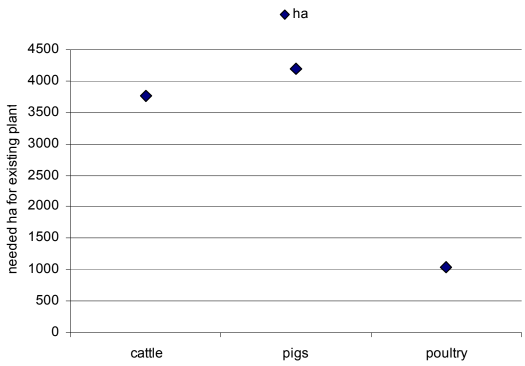

Figure 7 Needed area for existing biogas plant

5 SHAPING AN INTEGRATED BIOGAS POLICY

Utilising any livestock manure as biogas substrate contributes to the GHG emission savings from agriculture and to nitrate savings. Although dairy cows indicate most individual GHG emission savings, pig manure is the most effective in providing marginal benefits for environmental, waste and agriculture policy from biogas. GHG emission savings from substitution effect indicate what energy form of biogas would be preferred.

The hypothetical agricultural biogas plant has demonstrated the marginal effect of biogas production and utilisation on environmental, waste and agriculture policy regardless on the context where biogas occurs. Conversely, biogas production and utilisation strongly depends on the context and general, aggregated numbers without including spatial distribution of livestock could provide misleading conclusions. As a rule of a thumb, biogas production would occur most likely in vicinity or at large, industrial type of farms. To society as a whole, large farms could be perceived as a starting point for shaping the integrated biogas policy as the benefits from biogas bundle will be maximised. During the tailoring of biogas policy, it should not be forgotten that, utilising livestock manure for biogas production in the hypothetical biogas plant would generate 5 200 to 38 700 € in money terms from GHG emission savings from agriculture at current price (6) whereas this could rise up to 12 000 to 88 000 € if assumed price of 30-40 €/tCO_2 when the market is implemented.

In the absence of availability of concentrated biogas feedstock production, one of the indicators that could facilitate identification of "biogas context" is biogas density factor [19] that provides information on the feedstock concentration per unit of land. Put differently, if a region has ≥4 000 m3 or ≥16 000 m3 of biogas potential in a radius of 10 km and 5 km, respectively, the hypothetical biogas plant will be viable. The biogas density factor also reflects land use in respect of excess nitrate in the area.

The importance of biogas density and biogas context surfaces regional governments as the most important biogas market players in terms of implementing the integrated biogas policy. Once tapping the biogas context or region with high biogas potential, it is crucial to look for its socio-economic issues and land use. As previously said, by failing to create a favourable business environment for biogas developers and investors, government loses its opportunity to benefit from the biogas bundle. Cutting red tape and streamlining the biogas investment venture would be priority for both national and regional governments. Investment in low income rural communities would not be triggered by high feed-in tariff as investment still represents a barrier to enter the biogas market. A large number of farms with a low number of LU will call for a centralised biogas plant. Little or plenty agricultural area suitable for manure spreading could also modify biogas policy in that particular context. The existing business environment could influence demand for a particular energy form from biogas. In case of rural communities, biogas plant could increase commodity prices and suffocate existing agro-food industries by changing the flow of goods in that community. Spatial planning office has a crucial role in ensuring sustainability of biogas production and utilisation within the context for which it is responsible. Those are only few examples of how biogas context is vital for biogas production.

6 CONCLUSIONS

The methodology provides simple guidelines on how to balance socio-economic costs and benefits from biogas production based on agricultural biomass, namely livestock manure.

In order to maximise benefits from biogas bundle, biogas policy should start by addressing the drivers of an investor that could be farmers, regional government or a third party or any combination of the three. A positive biogas investment environment opens with transparent and streamlined implementation procedures and continues with tailoring financial mechanisms that would meet socio-economic issues of investors.

Clear guidelines should help both regional and national authorities to achieve more with less by differencing support measures for biogas production targeting those areas where social benefits of biogas production are greater than costs.

7 NOTES

(1) i.e. average size of on-shore wind park is 2 MW, landfill gas power plant 4.4 MW, 1.2 MW is average size of wind turbine installed in Germany in 2008 etc.
(2) LU = Livestock unit
(3) MoE – Ministry of Energy or equivalent high-level national bod(ies) responsible for energy issues from biogas
(4) MoGHG – Ministry or equivalent high-level national bod(ies) responsible for meeting Kyoto target and GHG savings
(5) MoA - Ministry or equivalent high-level national bod(ies) responsible for agriculture
(6) www.pointcarbon.com, 13.17 €/t

8 REFERENCES

[1] J.B. Holm-Nielsen, T. Al Seadi, P. Oleskowicz-Popiel, The future of anaerobic digestiona and biogas utilisation, Bioresource Technology, In Press,

Corrected Proof, Available online 13 February 2009
[2] R. Braun and A. Wellinger, Potential of co-digestion. IEA Bioenergy, Task 37 – Energy from Biogas and Landfill Gas (2003), available at www.IEA-Biogas.net.
[3] L. Yu, K. Yaoqiu, H. Ningsheng, W. Zhifeng, X. Lianzhong, Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation, Renewable Energy, Vol. 33, Issue 9 (2008), pp 2027-2035
[4] IEA Task 37 Energy from Biogas and Landfill Gas
[5] E.K. Yiridoe, R. Gordon, and B.B. Brown, Nonmarket cobenefits and economic feasibility of on-farm biogas energy production, Energy Policy, Vol. 37, Issue 3 (2009), pp 1170-1179
[6] D. Rutz, R. Janssen, H. Prassl, Assessment of biogas policies in the European Union (2008), contribution to the deliverable 3.1 of IEE Big>East project, available at www.big-east.eu
[7] EurOberv'ER (2008): Biogas barometer – July 2008
[8] EC, An EU energy security and solidarity action plan - Energy sources, production costs and performance of technologies for power generation, heating and transport,{COM(2008) 781 final}
[9] T. Al Saedi at al., Biogas handbook, University of Southern Denmark Esbjerg (2008), ISBN 978-87-992962-0-0, available at www.big-east.eu
[10] Th. Amon, et al., Optimising methane yield from anaerobic digestion of manure: Effects of dairy systems and of glycerine supplementation (2006), International Congress Series 1293, pp. 217–220
[11] Institut für Energetik und Umwelt GmbH together with Bundesforschungsanstalt für Landwirtschaft i Kuratorium für Technik und Bauwesen in der Landwirtschaft e. V., Handreichung Biogasgewinnung und – nutzung, Bundesministerium für Verbraucherschutz, Ernärung und Landwirtschaft, Fachagentur Nachwachsende Rohstoffe e.V. Gülzow (2006), ISBN 3-00-014333-5
[12] IPCC Guidelines for national greenhouse gases inventories (2006), available at http://www.ipcc-nggip.iges.or.jp/public/index.html
[13] EC: Directive (91/676/EEC) concerning the protection of waters against pollution caused by nitrates from agricultural sources
[14] W. White, B. Kulisic, J. Domac, Economic and Social Drivers to Encourage Bioenergy Market Development, Proceedings from 15th European Biomass Conference and Exhibition – From Research to Market Deployment (2007)
[15] EC: RES-Directive (2009/28/EC)
[16] EC: 20 20 by 2020 Europe's climate change opportunity {COM(2008)19 final}
[17] D. Deublein, & A. Steinhauser, Biogas from Waste and Renewable Resources. An Introduction, WILEY-VCH Verlag GmbH & Co.KGaA, Weinheim, (2008) ISBN 978-63-527-31841-4
[18] Pravilnik o dobroj poljoprivrednoj praksi u korištenju gnojiva (OJ 56/08)
[19] B. Kulisic & V. Par: Agricultural potential for biogas production in Croatia, Agriculturae Conspectus Scientificus, Vol. 74, Issue II (2009), article in press