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The expansion of biogas fuelled power plants in Germany during the 2001–2010 decade: Main sustainable conclusions for Poland

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Abstract

In the period 2001-2010 the number of biogas fuelled power plants have increased in Germany by almost 20% year-on-year, from 1050 at the beginning of 2001 to 6000 at the end of 2010. The main drivers behind this rapid expansion were: (i) technological advancement, (ii) attractive financial incentives such as feed-in-tariffs, (iii) the search for increasing energy security and (iv) the strong German farming sector. Due to existing similarities between German and Polish economies, Poland has the potential to replicate Germany's example and Polish biogas energy might also undergo expansion at a similar rate in the near-term. This article reviews aspects of Polish energy policy and investigates factors that could provide impetus for an upsurge of agricultural biogas energy in Poland. It is emphasized that amendments to the Polish tradable certificate system are urgently needed in order to encourage investment into biogas energy. For instance, the introduction of biomass and technological bonuses could improve feedstock availability and boost the take-up of best available biopower technologies, respectively. Promising, but mostly unexplored feedstock potentials in Poland, such as energy crops, grasses, sorted municipal organic wastes and algae are discussed. The role of agrobiogas in the possible solving of Polish CCS dilemmas is explained. Further, it is shown that the cost of electricity is almost independent of the size of agrobiogas CHP power plants in the range of 0.2 to 5 MW_e. Therefore, agrobiogas energy could be dominated by small-scale agrobiogas power plants offering more green jobs and improved local waste management characteristics. New national and international research and development initiatives are needed in order to enhance the development of biogas energy in Poland.

Keywords: biogas, power plant, Germany, 2001--2010 decade, sustainable development, Poland

1. Introduction

In the European Union the leading countries in biogas energy field include Germany, Denmark, Austria and Sweden. During the period 2001--2010 Germany increased her number of biogas-based power plants from 1,050 installations in 2,000 to 6,000 installations in 2010 [1], i.e. by almost 20% per year. The main drivers behind this rapid expansion were:

- technological advancement
- attractive financial incentives such as feed-in tariffs,
- the search for energy security and

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- the strong German farming sector.

Budzianowski has recently asserted that bioenergy shows considerable economical capacity potential compared to other available renewable energy sources (RES) in Poland [2], especially in southern Polish regions [3]. In light of the existing similarities between Germany and Poland and the recent great step forward in biogas energy development in Germany, Poland could repeat her neighbor's achievements in the near-term. Well-designed economical incentives and continued technological advancement [2] are of fundamental importance for any meaningful investment in the biogas energy option in Poland.

This article reviews the Germany biogas story during the first decade of this millennium and characterizes recent biogas developments in Poland. There is a discussion of key biogas energy issues such as:

- financial incentives for biogas energy implemented in Germany and Poland,
- near-term availability of feedstock,
- the contribution of biogas energy to the easing of global warming concerns, and
- the optimization of the future Polish biogas energy system. In summary, the main sustainable conclusions for Poland are presented.

2. Biogas energy expansion during the 2001-2010 decade

2.1. Germany

There are two basic models for the implementation of agriculture-based biogas plants in the EU member states. The first model includes distributed farm-scale biogas power plants featuring co-digestion of animal manure and, increasingly, bioenergy crops usually from one single farm. Farm-scale plants are usually customarily attached to large pig farms or dairy farms. The second model includes centralized large-scale plants, which typically co-digest animal manure collected from several farms together with organic residues from industry and townships.

Germany is a leader in the application of distributed on-farm biogas systems, with over 6,000

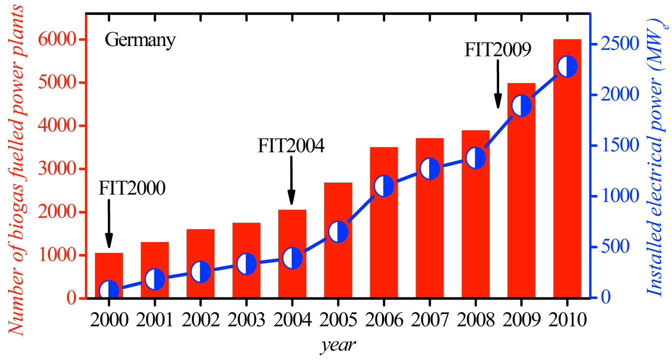

Figure 1: : Expansion of biogas fuelled power plants in Germany during the period 2001–2010 [1]

power plants currently in operation. The German government has also ambitious plans for future growth aiming to meet a target of 30% renewable energy production by 2020. To do so the number of biogas plants will have to increase to about 10,000--12,000. Denmark, in contrast, has chosen the route of centralized biogas plants, which is enhanced by well developed cooperation between farmers.

Biogas is mainly used for combined heat and power (CHP) generation, with the heat generated being used principally for heating anaerobic digesters and secondly for supply to local district heating grids. Dominant power technology is gas engine [4, 5]. In Germany a technological bonus applies to four novel biogas-related power technologies: fuel cell [6–9], gas turbine [10–12], organic Rankine cycle (ORC) [13] and Stirling engine [14]. Biogas can also be upgraded to biomethane, for use as a vehicle fuel [15] or for injection to natural gas grids [16]. A brief overview of power and upgrading technologies relevant to biogas energy can be found elsewhere [2].

The German Renewable Energy Sources Act of 2000 (Erneubare Energie Gesetz (EEG)) have introduced fixed feed-in-tariffs (FIT), which have had a marked impact on the diffusion rise of biogas energy in Germany. Fig. 1 shows the number of biogas fuelled power plants and installed electrical capacities over the period 2001--2010 in Germany. The EEG of 2000 set fixed feed-in-tariffs for 20 years (FIT2000). As a result 250 and 300 new biogas power plants were built; in 2001 and 2002, respectively. An amended EEG in 2004 introduced a new biomass bonus (FIT2004), thereby biogas production from energy crops has been substantially encouraged. Accordingly, 630 and 820 new biogas power plants were built in 2005 and 2006. In 2007 agricultural biomass prices rose considerably, which reduced the number of new power plants built in 2007 and 2008 to about 200 in each year. A further amendment to the EEG taking effect on 1 January 2009 increased the FIT basic rate and the biomass bonus (FIT2009). Consequently, the number of newly-built biogas power plants topped 1,000 in both 2009 and 2010. Fig. 1 also clearly demonstrates a steep increase in installed electrical capacities, observed since 2004. This is attributed to the implementation of biomass bonus (FIT2004), which boosted the availability of feedstock from energy crops in environs of existing biogas power plants. In 2010 the average output power of German biogas fuelled power plants was 0.38 MW_e.

2.2. Poland

During the period 2001–2005 biogas fuelled power plants were built in Poland only at municipal landfills and waste water treatment plants with the primary objectives being to reduce:

- unwanted methane emissions from landfills and
- the amount of sewage sludge generated by waste water treatment plants, respectively [17].

The Polish tradable certificate system (TC) designed to encourage investments into renewable energy sources (RES) went operational in 2005 (TC2005). The green certificates issued under the Polish TC system of 2005 are however not technology specific and, thus they have had little beneficial effect on the development of biogas energy in Poland. Besides, no biogas-related biomass bonus features in the Polish TC system. Consequently, during the period 2006--2010 new biogas power plants still were built mainly at landfills and municipal waste water treatment plants. In 2010 there were 149 of all biogas fuelled power plants of which only 11 (7%) were agricultural biogas power plants. In 2010 the average output power of Polish biogas fuelled power plants was 0.59 MW_e, i.e. was 55% larger than that of German plants.

Solid biomass is the dominant RES power technology in Poland. It is mainly utilized in co-combustion

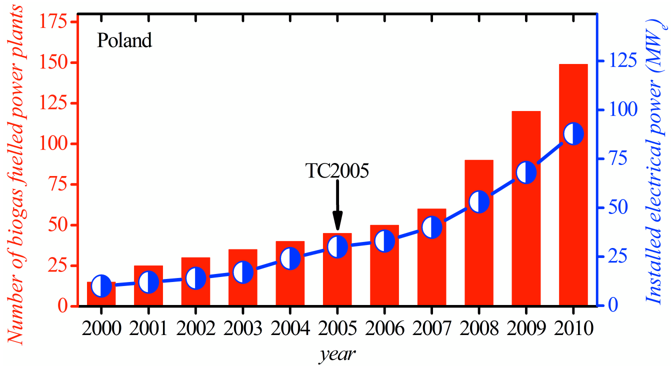

Figure 2: Expansion of biogas power plants in Poland in the period 2001--2010 [18, 19]

with coal. Solid biomass achieved an 85% share in the consumption of final energy in Poland in 2008, while the contribution of biogas energy was only 2.4% – (landfill biogas 0.61%, waste water plants-derived biogas 1.7% and agricultural biogas 0.05%) [21]. In contrast, the German biogas industry is dominated by agricultural biogas. Table 1 presents the numbers of agrobiogas fuelled power plants, which were built in Poland in the years prior to 2011. It is seen that new installed electrical power was: 0.95 MW_e in 2005, 0 MW_e in 2006–2007, 0.63 MW_e in 2008, 4.54 MW_e in 2009 and 2.86 MW_e in 2010. The average output power per agrobiogas power plant is 0.82 MW_e, which is relatively large. The dominant feedstocks are pig manure, organic wastes and maize silage.

3. Comparison of economical incentives for biogas power

Germany and Poland use different economical incentives to increase the share of electricity from RES. The German RES promotion system is price driven (i.e. feed-in-tariffs (FIT)), while the Polish RES promotion system is based on quotas (Tradable Certificates (TC)). A FIT system can be easily made as technology specific, thereby reducing the producer surplus for the cheapest technologies (e.g. large-scale hydro) while it can promote the development of energy from RES with potential for achieving large capacities in the near-term, such as biogas energy [2]. Therefore, FIT systems are well-suited to support of distributed power systems using RES, like biogas-based power systems.

Table 1: Agricultural biogas fuelled power plants built in Poland prior to 2011 [20]

Power plant	Year	Output electrical power, MW_e	Feedstock
Pawłówko	2005	0.95	organic mix
Płaszczyca	2008	0.63	pig manure, silage, oil-derived wastes
Kujanki	2008	N/A	pig manure
Koczała	2009	2.13	pig manure, silage, food industry derived wastes
Liszkowo	2009	2.13	food industry derived wastes
Niedoradz	2009	0.25	pig manure, chicken wastes
Studzionka	2009	0.03	chicken wastes, pig manure
Nacław	2010	0.63	manure, maize silage
Świelino	2010	0.63	manure, maize silage, organic wastes
Kalsk	2010	1.00	maize silage, sorgo, manure
Kostkowice	2010	0.60	manure, organic wastes

Table 2: Financial incentives for biogas fuelled power plants in Germany per the EEG feed-in-tariff (FIT) law as of 2010 [1]

Output electrical power of biogas fuelled power plant, MW_e	0–0.15	0.15–0.50	0.50–5	5–20
	Premiums for biogas fuelled power plants, €/MWh_e			
Basic rate	115.50	90.90	81.70	77.10
Biomass bonus	69.30	69.30	39.60	0.00
Manure bonus	39.60	9.90	0.00	0.00
Heat bonus (CHP)	29.70	29.70	29.70	29.70
Technology bonus	19.80a	19.80a	19.80a	0.00
Landscape preservation bonus	19.80	19.80	0.00	0.00
Formaldehyde bonus	9.90	9.90	0.00	0.00
Total maximal premiums	303.60	249.30	170.80	106.80

Notes – A 1% annual degression is applied to the tariffs (the tariffs are thus reduced for 2011). The biomass bonus is paid when raw materials are specifically grown for digestion. Manure bonus is paid when at least 30% of feedstock by volume is used. Heat bonus is included to encourage waste heat utilization. Technology bonus applicable with use of e.g. fuel cells, gas turbines, organic-Rankine cycles (ORC), Stirling engines. Landscape preservation bonus can be claimed when use of feedstock is associated with a landscape preservation activity. Formaldehyde bonus is included to encourage formaldehyde management. a – for installations upgrading biogas to biomethane with the size from 350 to 700 Nm^3/h the technology bonus is €9.90/MWh_e.

3.1. Germany

German financial incentives that arise from the EEG feed-in-tariffs (FIT) are shown in Table 2. Total maximum premiums for new biogas fuelled power plants decrease from 303.60 to €106.80/MWh with increasing installed output power of biogas plants. The German FIT system includes several bonuses that constitute energy policy tools enabling policy makers to efficiently shape their desired biogas power system.

3.2. Poland

In Poland financial incentives are lower than those in Germany and decrease from 149.38 to €133.02/MWh with increasing installed power of biogas plants. The main difference lies in the support given to small-scale biogas power plants having output electrical power of less than 0.50 MW_e, Tab. 3, which is about 50% lower in Poland than in Germany. This feature of the Polish TC system is central for agrobiogas expansion, since Polish farms are relatively small and thus farmers are interested principally in small-scale biogas plants. It is expected that the current Polish TC system (i.e. without any modifications in future) will encourage investments mainly in medium to large-scale biogas fuelled power plants. This is however to some extent consistent with the Energy Policy of Poland [22, 23], which projects the implementation of one biogas power plant in each Polish gmina administrative district having appropriate biomass resources.

In both compared countries biogas fuelled power plants can also sell heat to district heating grids [24] and in Germany biomethane to natural gas grids. Biomethane injection is soon to be fully regulated by law in Poland and the related system of tradable brown certificates is to be introduced.

4. Promising but mostly unexplored feedstock potentials for sustainable biogas production in Poland

The central issue of biogas-based power generation is the availability of cheap feedstock in sufficient quantity. There are several sources of valuable feedstock for biogas production of municipal, agricultural and industrial types. They include sewage sludge [17, 25], animal residues, energy crops, grasses, organic sorted wastes, landfilled wastes, etc. The development of biogas production creates an additional demand for organic feedstocks, which otherwise have limited availability, thereby increasing feedstocks prices and consequently developing a feedstock market.

In Poland, the realistically available feedstock potential for the production of biogas in the by-products of agriculture and the agricultural and food industry is approximately 1.7·109 m^3 of biogas per year, but after including energy crops, it could reach 6.6·109 m^3 of biogas per year. The Energy Policy of Poland until 2030 [22] plans that biogas fuelled power plants will be built in the gmina administrative districts having organic wastes or large arable and grass lands from which sufficient amounts of surplus biomass may be obtained. This constitutes a type of harmonization of the state's national agricultural priorities with those of the EU's Common Agricultural Policy [23].

Feedstocks are a subject in themselves and deserve to be explored at some length from the perspective of biogas production. An overview follows of little-appreciated feedstocks showing great potential.

4.1. Energy crops

95 % of German biogas fuelled power plants use waste from crop and livestock farms such as slurry, manure and dedicated energy crops. In contrast to many other countries (including Poland) where most biogas is produced using organic municipal waste, Germany relies mainly on farms for its raw material. This country has also proved the viability of producing biogas using organic waste from the food industry. The electricity production from biogas in Germany accounts for half of that of produced in the European Union.

Simon and Wiegmann [26] have shown that the Polish agricultural bioenergy sector has the potential to generate 10–25% (forest and waste biomass not considered) of the total energy supply in 2030, which is even higher than that projected for Germany. De Wit and Faaij [27] have shown that the costs of biomass cultivation are substantially lower in Poland – wages are 21% of those in Germany (€3.05/h versus €14.13/h), fertilizer prices are more

Table 3: Financial incentives for biogas fuelled power plants in Poland per the system of tradable certificates (TC) as of 2011, assumed €/PLN = 4.00 [20]

Electrical power of biogas fuelled power plant, MW_e	0–1	>1
	Premiums for biogas fuelled power plants, €/MWh_e	
Price of electricity supplied to electrical grids	49.30	49.30
Green certificates (RES)	68.93	68.93
Yellow certificates (CHP < 1 MW_e)	31.15	0.00
Violet certificates (CHP > 1 MW_e)	0.00	14.79
Total maximal premiums	149.38	133.02

Notes – Green certificates are renewable energy source (RES) premiums and apply to all biogas fuelled power plants. Yellow certificates are small-scale combined heat and power (CHP) premiums and apply for biogas fuelled power plants having electrical power smaller than 1 MW_e and involving CHP. Violet certificates are large-scale CHP premiums and apply for biogas fuelled power plants having electrical power larger than 1 MW_e and involving CHP. In near future brown certificates for biogas-to-biomethane upgrading and injection into natural gas grids is to be introduced.

than 50 % lower and land costs are 27% of those in Germany (very suitable land: €72 ha/y versus €267 ha/y in Germany). Therefore, agrobiogas is definitely a promising RES power technology for Poland, at least in the time frame of next 20–30 years.

4.2. Grasses

In the modest European climates relevant for central EU-countries, such as Poland or Germany, biogas can be produced from grasses. The grass biogas system has a number of distinct advantages over other feedstock. Firstly, grass-derived biogas does not need a change in land use, i.e. grass does not require arable land to grow. Grassland does not need to be plowed and planted each year, unlike maize or wheat which require annual plowing. Grass feedstock is also well-suited for highly urbanized areas where grassland can simultaneously perform several other social functions, if needed. Grass is particularly promising in Ireland which has 8% of the cattle population of the EU with less than 1% of the human population; as a result 91% of agricultural land in Ireland is under grass.

4.3. Organic wastes

Organic wastes from the food industry or agriculture have great potential and they are well understood and widely used for biogas production. One unexplored organic waste-based feedstock relates to municipal wastes sorting. Namely, Cherubini et al. [28] have presented the Life Cycle Assessment (LCA) of four municipal waste management strategies: (i) landfilling, (ii) landfilling with biogas uptake, (iii) sorting and combined incineration/anaerobic digestion, and (iv) direct incineration. The results of their study clearly show that a sorting plant coupled with power and biogas production plants, strategy (iii), is the best strategy for municipal waste management, since it can meet 15.47% of electricity demand and 8.24% of natural gas demand of the city of Roma. Also this strategy has the lowest net environmental impact, quantified by global warming potential (GWP – i.e. net CO_2 emission) and acidification potential (AP – net SO_2 emission) as well as land use (net ha/tonwaste). Interestingly, all those three key indicators beneficially attains negative values in regard to biogas energy (see Section 5 of the present article for further discussions). According to the sustainable sorting/incineration/digestion strategy, Fig. 3, the incineration of inorganic fraction of wastes can be achieved by combustion or gasification. The incineration of sorted wastes benefits from higher energy conversion efficiency than direct incineration of unsorted solid wastes. Organic sorted wastes are efficiently converted by anaerobic diges-

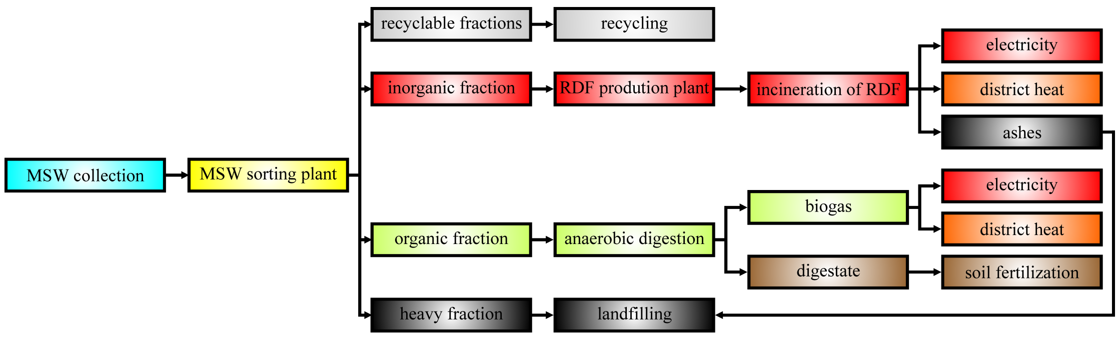

Figure 3: Sustainable strategy for municipal solid waste management involving sorting, incineration and digestion steps

tion. Valuable materials are recycled while only a minor part of wastes is landfilled.

4.4. Aquatic biomass – algae

Micro- and macroalgae have recently received increasing attention as a future promising feedstock for biogas production. They have three key advantages:

- offer biomass yields per ha and per year of 10--80 times larger than yields obtainable from other popular soil-based energy crops,
- are well suited for the fixation of CO_2 [29], and
- can be cultivated both on-land (e.g. in ponds) and off-land (e.g. as maritime plantations), thereby having almost unlimited bioenergy capacity potential.

This feedstock is currently not commercialized and needs research efforts. However, due to observed rapid development in biotechnological sciences it might become an important resource for biogas energy [30] in near future.

5. The contribution of biogas energy to easing global warming concerns

Climate warming is attributed in part to the accumulation of CO_2 in the atmosphere. Anthropogenic CO_2 emissions affect the equilibria of natural carbon cycles and CO_2 concentration in the atmosphere is increasing at a rate of around 2 ppm/year currently reaching around 390 ppm. At this rate the Copenhagen Accord target of 450 ppm CO_2/+2°C will be reached before 2040 [31].

The current article asserts that by an expansion in the use of biogas energy a valuable contribution to easing CO_2 induced global warming concerns can be achieved. Namely, Budzianowski has proposed [17, 32] that biogas conversion integrated with hydrogen production and carbon capture and sequestration (CCS) [33] can achieve negative atmospheric CO_2 emission. According to the proposed ORFC cycle considerable benefits arise from enrichment of process gas in CO_2 (up to 70% CO_2) compared with air coal-firing derived flue gases comprising less than 15% CO_2. Such CO_2 enrichment can lead to considerably reduced CO_2 capture costs in power plants utilizing the ORFC cycle. Biogas production-derived digestate, which is a valuable soil fertilizer, is another source of negative atmospheric CO_2 emission. Namely, the utilization of digestate leads to the accumulation of carbon in arable soils. Therefore, the life cycle assessment (LCA) of agro-biogas-to-CHP results in negative atmospheric CO_2 emission. Pöschl et al. [34] have reported the value of $-414\ \mathrm{kg}_{CO_2}$/MWh. This aspect relates only to biogas energy [35] and it is not featured by any of other RES such as hydro or wind. It arises from the fact that biomass comprises carbon entirely accumulated from the atmosphere (plants are unable to assimilate non-atmospheric carbon) and a part of this carbon is stored in soils as digestate or can be captured and sequestered to e.g. fuels. The concept of negative atmospheric CO_2 emission in relation to the conversion of biogas energy is presented schematically in Fig. 4. It is believed that this unique feature of biogas energy can substantially contribute to solving current Polish CCS dilemmas. However, the first necessary step must be a rapid expansion of biogas

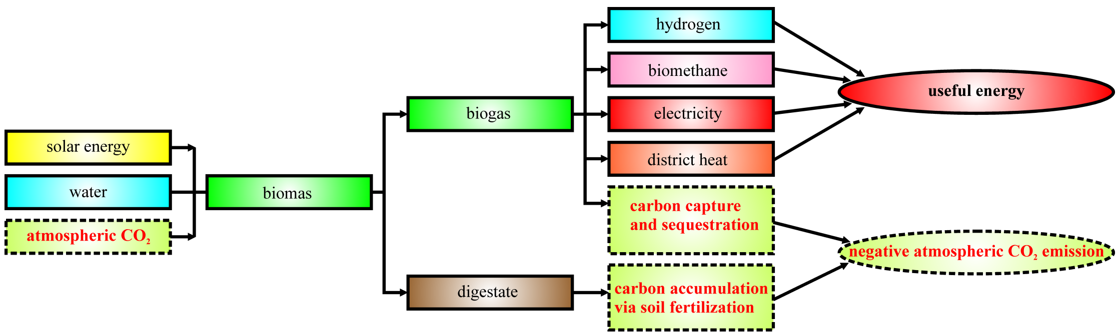

Figure 4: The contribution of biogas energy conversion to easing global warming concerns via negative atmospheric CO_2 emission [17]

production in Poland.

6. Towards optimization of the Polish agrobiogas energy system

6.1. The optimal size of agrobiogas power plants

The average output power of all 11 existing Polish agricultural biogas fuelled power plants is 0.82 MW_e, compared to the 0.59 MW_e for all Polish biogas plants (including landfill and waste water treatment plants). It is also larger than the average German output power of 0.38 MW_e. This reflects the fact that the Polish agrobiogas energy system has adopted a more centralized direction than the German system. Walla and Schneeberger [36] have found that for maize silage-derived biogas fuelled CHP power plants having output power ranging from 0.20 to 5.00 MW_e the costs of electricity (COE) are almost independent of the size of the agrobiogas power plants (see Fig. 4 in [36]). This effect arises from the fact, that the reduction of COE due to the increased energy conversion efficiency of a larger power plant [37] is compensated by the increase of COE due to increased maize transportation costs from longer distances. Therefore, all maize-based agrobiogas fuelled power plants having output power ranging from 0.2 to 5.0 MW_e have similar COEs. However, small-scale agrobiogas power plants enjoy better utilization of small-scale feedstock resources and have improved social (green jobs) and environmental (waste management) characteristics. Therefore, the support for small-scale agrobiogas power plants can be recommended for Poland.

6.2. Amendments to the Polish TC system

The Polish TC system contrasts poorly in comparison with the German FIT system in terms of unpredictability. In view of the variability in the economical environment and RES-related policy, the valuation of future prices of TCs set by a large degree of uncertainty [38]. This uncertainty impedes the optimization of agrobiogas fuelled power plants [39]. Investors therefore cannot calculate prospective incomes from newly proposed agrobiogas projects and thus can encounter problems with obtaining finance.

Besides, according to the current (2011) Polish RES-related law, the main stream of financial support is directed to projects such as old large-scale hydro power plants. This is costly for taxpayers and does not promote the development of new RES investments in Poland. Therefore, an urgent amendment to the Polish TC system is required. The changes should (i) implement incentives being specific in regard to RES technology [40], should (ii) promote distributed energy system with small-scale power plants, and should (iii) promote new investments by the inclusion of an depreciation criterion. Those amendments are currently under development in the Ministry of Economy [2]. The other necessary amendments include the introduction of biomass and technological bonuses which could improve feedstock availability and boost the take-up of best available biopower technologies, respectively.

6.3. Drivers and barriers influencing the expansion of agrobiogas energy

Table 4. provides a comparison of main drivers and barriers influencing the expansion of agrobiogas energy in Germany and Poland.

Table 4: Comparison of main drivers and barriers influencing the expansion of agricultural biogas fuelled power plants in Germany and Poland (2010)

Germany	Poland
Economic incentives	
• FIT system is RES technology specific and offers premiums fixed for 20 years,	• TC system is not RES technology specific, no fixed premiums are guaranteed,
• capital investment grants and soft loans have been used extensively in the past,	• capital investment grants and soft loans are mostly not RES technology specific,
Environmental context	
• 15% of electricity consumption from RES,	• 7% of electricity consumption from RES,
• target 30% by 2020,	• target 15% by 2020,
• large GHG emission (804 Mt_{CO_2}/year) [41],	• large GHG emission (305 Mt_{CO_2}/year) [41],
Energy security	
• 63% of oil and 80% of natural gas supplies are from import,	• 70% of natural gas supplies are from import,
• nuclear supplies 12% of energy but will be phased out,	• no nuclear power (the first nuclear power plant is projected by 2022),
Agricultural context	
• 6,000 on-farm biogas fuelled power plants with the target of 10,000–12,000 by 2020,	• only 11 agrobiogas fuelled power plants but the strong support from the Ministry of Economy is observed [20],
• the German FIT system offers biomass bonus which boosted energy crop cultivation,	• the Polish TC system offers no premiums for the utilization of biomass in agrobiogas power plants thus energy crops cultivation is not promoted,
Technological context	
• 1000 scientific publications on biogas energy per year,	• scarce scientific publications on biogas energy, particularly in technological fields [2, 7–13, 17, 42, 43]
• technological advancement in anaerobic digestion and biogas-relevant power technologies,	• little technological potential in regard to anaerobic digestion and biogas-relevant energy technologies,
• technological bonus offered by the German FIT system,	• no technological bonus offered by the Polish TC system,
• large involvement into biogas national and international R&D programs,	• little involvement into national and international R&D programs,
• technology readily available to German farmers (TV, Internet, organizations such as Fachverband Biogas e.V. [1]).	• technology [2] still poorly disseminated among potential investors [20].

7. Conclusions

From the provided analyzes of the expansion of biogas fuelled power plants in Germany during the period 2001--2010, the following main sustainable conclusions for Poland can be drawn:

- urgent amendments are needed to the Polish tradable certificate system directed at
  - promoting of agrobiogas technology,
  - new investments into agrobiogas power plants and
  - expanding of distributed small-scale power generation systems,
- the Polish TC system needs the implementation of a biomass bonus to boost the cultivation of energy crops and thus expand feedstock availability and biomass market,
- the Polish TC system needs the implementation of a technological bonus to encourage a shift toward best available power technologies,
- largely overlooked promising feedstoks include: energy crops, grasses, sorted municipal organic wastes and algae,
- agrobiogas energy can contribute to the solving of Polish CCS dilemmas by making use of the negative atmospheric CO_2 emission concept [17],
- small-scale agrobiogas power plants should be supported in Poland; since the cost of electricity is almost independent of the size of agrobiogas power plants in the range from 0.2 to 5 MW_e, thus agrobiogas energy is well suited for a distributed energy system, while small-scale biogas power plants offer more green jobs and improved local waste management. Therefore, small-scale agrobiogas power plants can be recommended for Poland,
- with an economical potential of 6.6·109 m^3 biogas per year the development of biogas energy can contribute significantly to the energy safety of Poland,
- new agrobiogas research and development projects should be initiated under national strategic and EU framework programs.

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Nomenclature

CCS – carbon capture and sequestration

CHP – combined heat and power

COE – cost of electricity

EU – European Union

FIT – feed-in-tariff

GT – gas turbine

GUS – Główny Urząd Statystyczny (Polish central statistical office)

IGCC – integrated gasification combined cycle

LCA – Life Cycle Assessment

MG – Ministerstwo Gospodarki (Polish Ministry of the Economy)

NFOŚiGW – Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej (National Fund for Environmental Protection and Water Management)

R&D – research and development

RDF – refuse derived fuel

RES – renewable energy sources

TC – tradable certificates

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