Ecological, technological and economic advantages of co-digestion for biogas production

Mirko Barz*

Hochschule für Technik und Wirtschaft (HTW) – University of Applied Sciences Berlin, Germany

Abstract:
Co-digestion is the simultaneous digestion of mixture of two or more substrates and a promising opportunity for the utilization of agricultural residues. Studies demonstrated that digestion of a variety of substrates, especially the utilization of animal manure together with solid agricultural residues and/or energy crops improves the nutrient balance and the anaerobic digestion process is more stable. Further advantages are an optimized use of fermenter volume which will result in increased plant capacities and the equalization of solid matter distribution in the fermenter. Using Agricultural waste as energy source is an effective solution for waste management and can reduce environmental problems as well as global warming [6]. The utilization of agricultural residues as source for biogas production will furthermore contribute to economic, environmental and social sustainability.

Keywords: *Agricultural residues; co-digestion; biogas; nutrient balance*

**Corresponding author. E-mail address: barz@htw-berlin.de*

1. Introduction

Caused by the tropical and sub-tropical climate conditions in many of the Southeast Asian (SEA) countries, the average productivity of biomass is 2–3 times higher than that of biomass grown in the temperate regions. Furthermore, most of the economies are characterized by an agricultural and agro-industrial economy, producing huge amounts of agricultural residues and wastes that can be used as feedstock for energy generation. It is estimated that if only all process-based agricultural residues alone would be used, they could contribute to nearly 25% of the total primary energy production of the countries (Barz and Delivand, 2011).

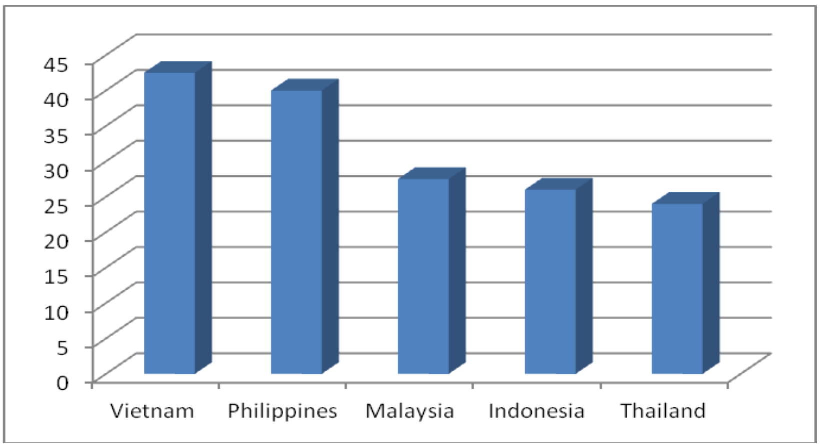

Fig. 1 Energy potential of agro processing residues as percentage of total primary energy production (Source: www.fao.org).

2. Agricultural residues as biofuels

Currently, around 5.1 billion dry tones of agricultural residues are produced globally (IEA, 2010). This amount represents approx. 75 EJ, or respectively 15% of the current global primary energy demand of 500 EJ. Depending on the location it is assumed that 25–50% of the agricultural residues could generally be used for bioenergy production on a sustainable basis. Examples of such agricultural residues, available in huge amounts and suitable for bioenergy production, are crop residues such as straw (as a field based residue) or husks (as a process based residue), animal manures and slurries and a huge variety of byproducts from industrial processing of agricultural products such as bagasse from the sugar industry, empty fruit bunches (EFB) from palm oil industry and various wastes from food processing industries. Within the different sources of agricultural waste we have to distinguish between those residues that are predominantly dry such as crop residues (e.g. rice straw and husk) and more suitable for thermo-chemical conversion routes and residues which are predominantly wet such as e.g. fruit residues and more suitable for biogas production. The following paper will focus on biomass sources and technologies which can be used for biogas production.

1.1. Suitable substrates for biogas production in SEA countries

In many of the SEA countries the food production is much more important than in Europe and competes to the production of energy crops (Plöchl and Heiermann, 2006). Using agricultural residues we have no direct competition with food or feed production, no additional land is required and the energetic use can reduce environmental problems (e.g. harmful emissions from open-air dumping of the biogenious wastes) and reduce fossil fuel based GHG emissions. Furthermore the decentralized local utilization contributes to income generation and rural development. Favorable substrates for biogas production are those that are wet such as e.g. waste from the cassava and starch factories, Empty Fruit Bunches (EFB) from Palm Oil Industries, the organic fraction of municipal waste and a wide variety of fruit residues such as banana and pineapple waste.

An overview about Methane yields gained from different tropical substrates after approx. 28 days of batch digestion experiments under mesophilic conditions (adopted from different studies) is given in Table 1.

Table 1 Methane (or biogas yields from different tropical substrates)

Substrate	Organic dry matter in %	Methane yield in Nm^3/t_{ODM}
Banana peel *[1]	87 - 94	243 – 322
Citrus waste *[1]	89 - 97	433 – 732
Coriander waste *[1]	80 - 86	283 – 325
Mango peel *[1]	89 - 98	370 – 523
Oil palm fibre *[1]	94	183
EFB *[3]	79 $_{(a)}$ - 84 $_{(b)}$	200$_{(a)}$ – 400 $_{(b)}$
Onion peels *[1]	88	400
Pine apple waste *[1]	93 - 95	355 – 357
Pomegranate *[1]	87 - 97	312 – 430
Sapote peels *[1]	96	244
Tomato waste *[1]	93 - 98	211 – 384
Water hyacinth *[1]	81	211 – 310
Coffee waste (pulp) *[2]		380 (biogas yield)

*[1] adopted from (Plöchl and Heiermann, 2006), *[2] adopted from (Hoffmann et al., 2003), *[3] adopted from (Nieves et. al., 2011), digestion experiments OPEFB for 30 days
$_{(a)}$ = untreated substrate, $_{(b)}$ after pretreatment with NaOH for 60 min

As shown in Table 1 the methane yields from tropical crop residues cover a wide range of values and especially the methane yields of tropical fruits are comparable with high yield usually produced by using energy crops such as maize in Europe (Plöchl and Heiermann, 2006).

1.2.Advantage of using agricultural waste for biogas production

Agricultural residues are abundant in SEA, but most of them are not applied efficient for energy purposes until now. Normally, large amounts of the residues were dumped into the environment where the anaerobic digestion naturally occurred. Consequently, the environmental problems such as land, surface & ground water pollution, ammonia leaching including the formation of methane as an important GHG from oxygen deficit condition occur. Using Agricultural waste as energy source is an effective solution for waste management and can reduce environmental problems as well as global warming (Chulalaksananukul et al., 2012). The utilization of agricultural residues as source for biogas production will furthermore contribute to economic, environmental and social sustainability.

3. Co-digestion - an opportunity to reduce limitations of agro-waste utilization

Anaerobic digestion (AD) is a process where micro-organisms convert complex macromolecular carbon containing substances (carbohydrates, fats, proteins etc.) to biogas, which consists of methane (CH_4) and carbon dioxide (CO_2). Some organic matter remains even after the digestion step (called digestate or digester residue) and is suitable to be used as fertilizer in agriculture. Co–digestion is the simultaneous digestion of a mixture of two or more different substrates. The most common case is when a main basic substrate (e.g. animal manure or sewage sludge) is mixed and digested together with a variety of additional substrates (e.g. energy crops or agricultural residues). AD has a long history and was traditionally a single substrate, single purpose treatment. Recently, it has been realized that the anaerobic digestion process is more stable when the variety of substrates is used (Wu, 2000). Studies demonstrated that using co-substrates in anaerobic digestion system improves the biogas yields due to the positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates (Aragaw et al., 2013).

1.3.Advantages of Co-digestion

Main advantage of co-digestion is an improved nutrient balance and the increase of the digestion performance (Barz, 2014). An overview about the minimum requirement for nutrient supply for methane producing bacteria is shown in Table 2.

Table 2 minimum requirement for macro and micro nutrient supply for methane producing bacteria

Macro Nutrients [g/l]								
C:N	N_{ges}	P	S	K	Mg	Na	Ca	Fe
10 - 45	0,15 – 0,45	0,05 – 0,15	0,05 – 0,1	0,075 – 0,25	0,01 – 0,04	0,045 – 0,2	0 – 0,075	0,01 – 0,2
Micro nutrients [mg/l]								
Ni	Co	Mo	Se	Cu	Zn	Mn	Wo	B
0,5 – 30	0,5 – 20	0,1 – 0,35	0,1 – 0,35	0 – 0,75	0 – 3	0 – 0,1	0,1 – 0,35	ca. 0,1

Quelle: Prof. Michael Nelles, Universität Rostock

Concerning macro nutrients, a nutrient ratio C:N:P:S of 300 - 800:15:5:5 is required to achieve optimal digestion performance (e.g. C = 8 g/l, N = 150 mg/l, S = 50 mg/l and P = 50 mg/l) and concerning micro nutrients concentrations of 0,1 mg/l for nickel, selenium and cobalt are essential for the methane producing bacteria. Animal manure e.g. is characterized by a low C/N ration, high ammonia content, high alkalinity and high contents of micro/macro nutrients. On the other hand, plant materials such as crop residues are characterized by a high C/N ratio (high carbon content), low alkalinity and a lack of macro/micro nutrients. So the co-digestion of animal manure with crop residues will lead to an optimized C/N ratio, an increase of the buffering capacity (Ammonia-Ammonium buffer + Carbon dioxide - Hydrogen carbonate buffer) of the system and ensure a max. use of fermenter volume (more biodegradable material in the fermenter). Further advantages are possible increased plant capacities and the equalization of solid matter distribution in the fermenter (Barz, 2014).

1.4.Technical requirements

For economic reasons the co-digestion of wet substrates like animal manure or waste water together with co-substrates like agricultural wastes or energy crops will get more and more important. In many cases this process will require an improved pretreatment of the substrates. The pre-treatment steps might include size reduction of the substrates, sieving and mechanical pre-treatment to ensure a homogenized and readily biodegradable substance, the removal of indigestible and unwanted components (such as plastic, metals) and some substrates may require pasteurization (Braun and Wellinger, 2003). Furthermore increased mixing requirements/improved mixing devices are recommended to ensure optimal digestion conditions. For this reason plug flow digester with paddle agitators or CSTR technologies are recommended technical solutions for the implementation of such co-digestion processes. Additional technical equipment might be required to avoid scum and sink layers in the digester and to remove sediments from the digester.

4. Conclusion

Digesters used only for animal manures or wastewater treatment facilities provide often relative low gas biogas yields. The addition of energy-rich organic waste materials (e.g. agricultural residues, Fats, Oils, and Grease (FOG) and/or food scraps) as co-substrates can contribute to produce more biogas and finally more electricity with marginal additional cost. Mixing of different substrates (e.g. co- digestion of animal manure and crop residues) will improve the process stability by improved nutrient supply and increased buffering capacity. Furthermore co-digestion will result in a higher flexibility to be able to compensate seasonal mass fluctuations of single substrates.

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