Turning a waste producer into an energy producer

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Abstract. The paper focuses on the possibility to turn waste generated by farms into biogas, which can be used for electricity and heat generation, covering own use or even more. Three case studies, all based on experiments, are presented, the first two revealing data concerning the potential energy development from the waste, as energy carrier, the third, run on a very modern lab facility, demonstrating the high potential of the manure as renewable bio-energy source. All are based on anaerobic biogas production.

1. Preamble
Organic waste is a large source for the future bio-energy, considered a promising source of clean energy able to provide heat, electricity and transport fuel. It is known that Biomass sources for energy include wood and wood processing wastes (firewood, wood pellets, and wood chips, lumber and furniture mill sawdust and waste, and black liquor from pulp and paper mills), agricultural crops and waste materials (corn, soybeans, sugar cane, switch grass, woody plants, and algae, and crop and food processing residues), biogenic materials in municipal solid waste (paper, cotton, and wool products, and food, yard, and wood waste), animal manure and human sewage [1].

By 2018, bio-energy’s total consumption reached a considerable contribution in the EU-28 (Table 1, and Figure 1), even Romania is weakly represented.

Table 1. Fuels inputs for electricity generation in EU and the Member States by 2018 (in ktoe) [2].

|          | ktoe | Solid fossil fuels | Oil and petroleum products | Gas | Nuclear | Non-renewable waste | Other non-Renewables | Renewables | Total Biomass |
|----------|------|-------------------|----------------------------|-----|---------|---------------------|-----------------------|------------|---------------|
| EU27     | 571.978 | 139.412            | 13.856                     | 86.942 | 195.738 | 8.513                | 11.897                | 115.620    | 41.294        |
| EU28     | 627.145 | 143.415            | 14.264                     | 108.100 | 209.799 | 9.671                | 12.377                | 129.519    | 48.722        |
| RO       | 12.339  | 4.239              | 209                        | 2.604 | 2.877   | 0                   | 34                    | 2.375      | 160           |

According to the EU policies [4], bio-waste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, agriculture, animal husbandry and comparable waste from food processing plants. Thus, manure (from cows, pigs or chickens) can also be turned into a bio-energy resource, being considered biomass, as well. In principal, the processes for obtaining energy from biomass are based on the ability of microorganisms to ferment biomass (ie organic compounds such as sugars found in organic matter) and to produce other compounds, which may have a higher calorific value (for example ethyl alcohol, methane).
In recent years, care for the environment has led to the development of technologies to reduce pollution. These include anaerobic fermentation of manure from animal farms, and thus stop the release of methane (CH\textsubscript{4}) into the atmosphere. It is captured in biogas plants and converted by combustion into bio-energy, emitting of course CO\textsubscript{2}, considered neutral (green), and having a much lower greenhouse effect (21 times lower) than methane CH\textsubscript{4} [5].

![Figure 1. Share of biogas within the total bio-energy gross inland consumption in 2018 (in %) [3]](image)

Recent major bio-energy development indicates that the adopted 2030 climate and energy framework sets three key targets for the year 2030 (based on 1990 levels): (1) At least 40 % cuts in greenhouse gas emissions; (ii) At least 27 % share for renewable energy; (iii) At least 27 % improvement in energy efficiency.

The framework is also in line with the longer term perspective set out in the Roadmap for moving to a competitive low carbon economy in 2050, the Energy Roadmap 2050 and the Transport White Paper [7]. In contrast to the Renewable Energy Directive, the Climate and Energy Package sets neither specific sub-targets for any of the sectors, nor binding targets for individual countries.

2. Case studies for Romania

The article refers to case studies, specific to waste generated by Romanian farms, demonstrating that, by a sustainable waste management and applying the concept waste to energy, the benefits for farms are real positive and concluded, in comparison to the present situation, when waste is not used fully or properly, according to its energy content or valuable composition.

The production of biogas by using wastes is proposed and discussed, not only because it is a renewable energy source, neutral for the CO\textsubscript{2} exhausted, but also contributing to the reduction of emission of greenhouse gases to the free atmosphere. The organic matter (manure or other products containing organic substances) is closed in a sealed tank (called a fermenter, or digester), to perform anaerobic fermentation. In order to promote bacterial activity, a temperature of at least 20 °C must be maintained in the fermenter. Higher temperatures, up to 65 °C, reduce both the duration of the process (the time it takes for bacteria to produce biogas) and the volume of manure required, by up to 40%. Although the number of bacterial species that act at medium temperatures (mesophilic bacteria) is higher than that of those that love higher temperatures (thermophilic), the latter are more active and produce more methane. But directing a process at high temperature is more complicated because temperature fluctuations reduce the activity of thermophilic bacteria.

The gas produced from anaerobic fermentation contains methane, carbon dioxide (usually about 90 % of the total), small amounts of hydrogen sulphide, nitrogen, hydrogen, methylmercaptans and oxygen. Of these, only methane is a combustible gas, and the energy of the biogas obtained depends
on the percentage of methane it contains (it can vary between 55 and 80 % by volume). For example, a biogas that contains 65 % by volume methane produces about 2.1. MJ/m³ N [8]. Simple biogas installations can be built on farms, consisting of covered lagoons, which produce biogas, used for heating or to produce electricity. For example, a displacement fermenter can process around 30,000 liters of manure / day, the amount produced by approx. 500 cows. If biogas is used to power a generator, it can produce more electricity and hot water than the farm consumes. Very often, in fermenters, a mixture of animal manure with other products containing fermentable carbohydrates (corn silage or other products, by-product or waste, milk residues, depending on availability) is used / fed.

The importance of temperature and pH, as well the used co-substrates upon the methane generation, are analyzed in several articles [9], [10].

In Romania, because the high costs for the electricity paid by industrial consumers, competitive uses of own waste could be a real option to gain not only on the economic side, but also on the sustainability of the secure development of the industrial producer. Still, the investments are quite poor, up to now, despite the general tendency of putting more value on bio-energy, in the member states (Figure 2), by enlarging the modern Renewables’s applications for electricity energy generation, and reducing the traditional biomass consumption (originally coming from forests).

According to [11], in Romania, one has to look on the experience of the other countries with already developed bio-energy sector (e.g., Sweden, Germany) in order to avoid any technical and, also, socio-economic obstacles. Despite of having a large biomass resource potential, financial, administrative and regulatory barriers are often indicated. High investment and operational costs, difficulties in accessing bank loans as well as lengthy administrative procedures are some of the specific barriers towards development of representative, industrial bio-energy projects. After 2016 no new plants have been erected, based especially on the lack of financial support for small units and necessity to develop heat and electricity in an important amount (as mainly all possible projects).

Figure 2. Global primary energy demands by fuel, 1925-2019 [12]

2.1. Results concerning biogas generation from pig manure

The case study approached a methodology which evaluates the biogas production calculated on the amounts of generated waste. One proposes that the energy recovery occurs in combined heat and power unit (CHP), in order to mitigate the highest value of energy efficiency. The material used into experiments consisted of (i) pig sludge, and (ii) degraded two row barley (Figure 3). In order to correct the pH values during the process, one used a solution of NH₃, 20 % by mass concentration [13].

Figure 2 proves that, by using a combination with degraded cereal material, the overall quantity of the obtained biogas is improved. All data, for the R2 generalized case, and in reference to the energy consumption of the farm, were used as input flows for the BioGC simulation software.
Figure 3. Experimental facility and results concerning the CH₄ concentrations in batches R1 (based on 5.5 l pig sludge) and R2 (based on 5.5 l of pig sludge and 280 g degraded two row barley)

Figure 3 proves that, by using a combination with degraded cereal material, the overall quality of the obtained biogas is improved. All data, for the R2 generalized case, and in reference to the energy consumption of the farm, were used as input flows for the BioGC simulation software [14], in order to point economic issues. By assuming that the biogas is used in a CHP facility (having a thermal efficiency of 30 %, and an electrical efficiency of 36 %), based on the costs in Romania for the used fuels and investment, the real annual estimated profit after investments is 97,697 €/year. The costs assumed were:

- costs with electric energy farm demand:
  \[ C_{el} = 0.155 \text{€/kWh} \times 2089178 \text{kWh/year} = 323,822 \text{€/year} \] (1)

- costs with thermal energy farm demand:
  \[ C_{GPL} = 0.659 \text{€/L} \times 289148 \text{L/year} = 190,548 \text{€/year} \] (2)

- total costs of the energy farm demand:
  \[ C_{Prod} = C_{el} + C_{GPL} = 514,370 \text{€/year} \] (3)

- income after taking into account the annual investment for the CHP unit:
  \[ I_{ER} = 894,862 \text{ (income from electricity and thermal energy sales, and fertilizer sales presumed at 10 €/tN) - 282795 (total running costs} = 612,067 \text{€/year} \] (4)

2.2. Result for biogas production based on organic wastes (caw and pig manure, waste water, and mixtures)

The agro-industrial company from Curtici, Arad County, Romania applies an integrated farming and processing of bio-resources: (1) agricultural farming, (2) animal breeding (cattle and pigs), (3) food production (meat and milk products), (4) marketing finished agro (bio) products. The authors proposed the anaerobic digestion of organic wastes (Table 2) to generate biogas, in order to produce energy and organic fertilizer, which could further support the production of the farm [15].

Table 2. Organic waste streams in 2016

| Organic waste                        | Quantity | State |
|--------------------------------------|----------|-------|
| Pig slurry                           | 24000 t/y| liquid|
| Cow manure                           | 600 t/y  | solid |
| Slaughterhouse waste water           | 30000 t/y| liquid|
The enterprise’s energy demand by 2016 was 3,200 MW as electricity, and 3,054 MW (13,470 GJ) thermal energy, equivalent as natural gas consumption.

Figure 4: Experimental facility (Automatic Methane Potential Test System – AMPTS II, developed by Bioprocess Control Sweden AB: 1-Sample incubation unit, 2- bioreactors/digesters, 3-CO$_2$ absorption unit, 4-gas volume measuring device, 5-laptop for data recording, 6-plastic bags for CH$_4$ collection) and methane generation over incubation time [15]

In order to calculate the Primary Energy Savings indicators in accordance to the EU legislation protocol (EC Directive, Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, L 315/1, Official Journal of the European Union, Brussels, 2012), and the annual income and savings, two scenario of energy recovery were proposed:

- Scenario 1- all thermal energy is recovered and used (maximum potential of energy recovery scenario).
- Scenario 2 – one recovers only the thermal energy used in the process for digestion and the one for the existing facilities for the enterprise is used (worst case scenario).

Both scenarios presume the energy production using a CHP unit, by assuming best efficiency. Figure 4 presents both the lab facility, as well the CH$_4$ generation during 21 days, for this specific research. The calculated economic indicators are given in Table 3.

Table 3: PES, annual income and savings [15]

| Economic indicator                      | Scenario 2 | Scenario 1 |
|-----------------------------------------|------------|------------|
| Electrical efficiency of CHP [%]        | 37.71      | 37.71      |
| Thermal efficiency of CHP [%]           | 45.7       | 33.76      |
| Quality factor [-]                      | 125.478    | 112.428    |
| Minimal quality factor [-]              | 100.001    | 100.001    |
| **PES [%]**                             | **20.30**  | **11.05**  |
| PES [MWh]                               | 1.252      | 611        |
| Net heat extraction [MWh]               | 1.573      | 983        |
| Net electrical power [MWh]              | 1.761      | 1,761      |
| **Annual incomes [€]**                  | **175,690**| **156,022**|
| Cost of heat purchased [€] (Natural gas)| 52.447     | 32,779     |
| Cost of electricity purchased [€]       | 123.243    | 123.243    |
| **Annual savings [€]**                  | **22,866** | **3,198**  |
Thus, in comparison to alternative technologies for energy production, the proposed CHP energy recovery is consuming less primary energy for the same amount of energy as underlie the PES (power efficiency) indicators of 20.30 % for Scenario 1, and 11.05 % for Scenario 2.

2.3. Results concerning biogas generation from swine dejections

The experimental facility is a BioReactor (BRS), produced by Bioprocess Control Sweden AB (BPC), which is a leader in control technology on the research side and commercial applications for biogas production (Figure 5). The installation consists of 6 digesters with a volume of 2000 ml, but during use these digesters must be loaded up to a capacity of 1800 ml. The plant is a very efficient one offering several unique functions, which are important for anaerobic digestion.

Figure 5. Experimental BioReactor, formed by following components: 1- Multifunctional motor, 2- Rubber stopper with 2 metal tubes, 1 plastic tube and rotating shaft for mixing, 3- 2-liter glass reactor with 3 holes, 4- Thermostatic water bath, 5- Helical coupling, 6- Bent shaft rod / rotating shaft, 7- Gas measuring device, 8- Plastic screw cap with hole, 9- Plastic clamps for tubes, 10- Feeding funnel, 11- Silicone stopper, 12- Discharge tube, 13- Plastic screw cap without hole, 14- Laptop for data recording

For the experiment, liquid and solid manure were used as raw materials, thus wishing to determine through the process of anaerobic digestion, the potential that this raw material has in the production of biogas. All crucibles containing the same amount of raw material were numbered. The content was fed in the correspondent glass reactors, further nominated as AB (line 1), AB (line 2), AB (line 3) containing the liquid and solid manure (177 g liquid plus 9.1 g solid), while those containing solid manure crucibles were numbered B (line 4), B (line 5), B (line 6), all fed with the same amount of liquid manure, as the previous ones. The raw batches were preliminary analyzed (depicting main thermodynamic properties such as humidity, ash content, etc); also a inoculum was used, the same for all. The experiment took more than 30 days, and daily care was assured, by feeding the bacteria, at the same hour. Figures 6, 7, 8 and 9 present the results. It is remarkable to conclude that the AB batches were more active in biogas production (CH\textsubscript{4}). Unfortunately batch Nb B6 did not show a biogas
production, due to a preliminary malfunction (feeding in the first day). The gas flow for Batch AB (line 2) was the most remarkable one, from the point of view of the generated gas flow. The poorest were the results from lines 4 and 5 (both solid). The maximum was recorded in the final part of the experiment, day 33-34 (line 2 and 3). All experiments show a daily variation in the gas flow.

![Figure 6](image-url)

Figure 6. Gas flow rate recorded during the experiment

A very important parameter is the pH of the batches, as shown in Figure 7. The values vary between 7.6 to 7.9, but for the mixture probes (AB) the values are regularly lower.

![Figure 7](image-url)

Figure 7. pH variation for all probes in the 6 lines
The Wet Gas Yield ($Y_{\text{wet}}$) is calculated for the report based on the selected time units by only using the interpolated / averaged values. It is calculated as ratio between the average value of the gas flow $G$, expressed as Nl/day versus the fed amount average value, $F$, expressed in g.

The Organic Gas Yield ($Y_{\text{org}}$) is calculated for the report based on the selected time units by only using the interpolated/ averaged values. The specific biogas rate is expressed in Nl/l/day. It is calculated as ratio between the specific gas production $SPG$, as interpolated value, expressed in Nl/day, and the organic loading rate $VS$, interpolated value, expressed in gVS/l/day.

Both Figures 8 and 9 confirm the fact that the combinations liquid plus solid manure are offering better results, in comparison to using only liquid manure as raw material for the biogas production.
3. Conclusions
The research results conclude that waste from farms is very suitable to be used as raw material for biogas production. Thus manure (solid and liquid) from pigs, caws, waste water and mixtures were experienced and main results, based on own research, but connected to Romanian farms, are presented. The biogas production occurred in lab pilots, from simple ones to very sophisticated facilities, which record automatically all specific process data. Two case studies demonstrated that the energy recovered by using the produces biogas as fuel is worth to cover or even extend the necessities of the farms analyzed. One highlighted the possibilities of the energy recovery in suitable units by using own bio waste, to mitigate the highest value of energy efficiency and reasonable recover value by using cogeneration units (CHP) to turn the energy into heat and electricity.

The experimental data and calculations proved that the energy recovery on CHP units based on methane gas produced through anaerobic digestion is a reliable and economic technology, even not a zero emission one, with an uncomplicated maintenance and relatively short period necessary for implementation, as well recommended by the present EU legislation. Romania should and must benefit from the biogas technology much more in the near future, as it represents a bio resource, which can cover at least the energy consumption for farms, that regularly produce organic wastes, presently not used or only partially used. The waste producers can become economic by using their own waste and turn thus into energy producers.

References
[1] ***https://www.eia.gov/energyexplained/biomass/ accessed 10.09.2020
[2] ***Bioenergy Europe, Statistical Report 2020, Bio Electricity
[3] ***BioEnergy, Statistical Report, 2020, Biogas
[4] ***http://ec.europa.eu/environment/waste/compost/index.htm, accessed 01.09.2020
[5] ***www.dep.pa.gov/Citizens/JustForKids/Energy/Renewable/Biomass/Pages/Manure.aspx, accessed 25.08.2020
[6] ***Being wise with waste: the EU’s approach to waste management 2010, doi 10.2779/93543, accessed as https://ec.europa.eu/environment/waste/pdf/WASTE%20BROCHURE.pdf
[7] ***Bio-energy Countries’ Report, Bio-energy policies and status of implementation 2016, IEA
[8] Vințila T 2010 From manure to electricity, Ferma, NB, March 26
[9] Wächter A, Ione I and Wächter R 2016 Green energy recovery from farm pig manure, 8ème édition du COFRET en Energie, Environnement, Economie et Thermodynamique, Bucharest, 29-30 junie, pp 48-53
[10] Wächter A, Wächter R and Ione I 2016 Co-substrates influence on methane generation through waste water anaerobic digestion, Proceedings of the 5th International Conference „Ecology of urban areas, Zrenjanin, Serbia, pp 94-103
[11] Dumitru C and Ione I Bioenergy in Romania - A Short Overview of Biomass- and Biogas-Based Plants, Biomass Conference and Exhibition, DOI: 10.5071/27thEUBCE2019-1BV.8.26 Conference: 27th European, Lisbon, Portugal, May 2019
[12] ***IEA 2020 Energy Technology Perspectives, Chapter 1: Clean technologies-the state of play, pp 39
[13] Wächter A R, Ione I, Cioabă A E and Wächter M R 2016 Biogas recovery from a pig farm. Smithfield Bacova unit case study, European Biomass Conference and Exhibition Proceedings, pp 960-964
[14] ***BioGC, www.biogascalculator.wfgsha.de, accessed 10.04.2016
[15] Wächter A R, Ione I, Vințila T and Vaida D Increasing energy efficiency of an agro-industrial integrated process through anaerobic co-digestion of slaughterhouse waste water and farm manure 2017, European Biomass Conference and Exhibition Proceedings, pp 938-942