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ECONOMIC EFFICIENCY OF PROCESSING BIODEGRADABLE WASTE IN DRY ANAEROBIC DIGESTION AND COMPOSTING TECHNOLOGIES UNDER THE POLISH MARKET CONDITIONS

An economic analysis of the dry anaerobic digestion (AD) in Poland operated with various input streams has been presented, ranging from the organic fraction of residual waste to biowaste from various sources. The shares of individual costs and revenues change significantly in these operation options. Sensitivity analyses, performed under assumption of four different market conditions showed that the profitability of AD plants is unpredictable. Assuming the current legal situation, the final profit or loss of the digestion technology strongly depends on the prices of energy. The final economic output for the anaerobic digestion was compared to the output of an aerobic stabilization process.

1. INTRODUCTION

In recent years, waste management has become a priority issue in Poland, mainly because of its poor performance and the Polish membership in the European Union, which imposed the obligation of introducing European waste policy. One of the main targets to be implemented by 2020 is to limit the amount of biodegradable municipal waste going to landfills to 35% of the amount generated in 1995. In order to achieve a high level of environmental protection, countries belonging to the European Community should first restrict the generation of waste, reuse, recycle and recover as much as possible, and the remaining waste should be disposed in a responsible manner. The waste policy favors technologies with the lowest environmental impact and products that can be reused and recycled.

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Anaerobic digestion (AD) is one of the procedures allowing the processing of biodegradable waste, including recycling of the organic substance if the generated digestate can be applied as a fertilizer or soil conditioner. Moreover, at the same time it allows energy recovery from the organic matter through biogas utilization. The energy recovery in a cogeneration system allows generation of electricity and heat, both of which are considered energy from renewable sources. Usually part of the heat produced from biogas is used to maintain the correct temperature of the AD process and to heat or cool the buildings of the facility. A part of the electricity is also used for the own needs of the plant – especially for running the pre- and post-treatment machinery [1]. The excess energy can be sold to external recipients, which is a potential source of revenue for the plant operator. Many LCA analyses have shown that anaerobic digestion is a better way of processing biowaste than composting [2–5]. The main reason for that is the possibility to recover energy from biowaste without compromising its role as a fertilizer. This is a clear advantage over the composting process from the environmental point of view, however from an economic perspective a deeper inside is needed into all costs categories in order to assess the economic viability of both technologies.

In Europe today, around 244 AD plants exist processing municipal biowaste into biogas [6]. A number of different AD techniques finds application, which are usually distinguished on the basis of the operating temperature (i.e., thermophilic plants operate at around 55 °C (50–65 °C) and mesophilic ones at around 35 °C (20–45°C)), and the percentage of dry matter in the feedstock (i.e., dry systems with 30–40% of dry matter, wet systems with 10–25% of dry matter) [7]. Most of the existing AD plants process separately collected biowaste. Poland, in turn, has only just begun the construction and operation of biogas utilities for municipal waste, with some exceptions of older co-digestion and wet AD plants which were not very successful. The newly constructed plants apply dry AD technology, of which the first one (based on the Dranco technology) has been operated since 2010, three plants according to the Strabag technology have been operated since 2014, 2015 and 2016, one based on the Eisenmann technology since 2014, and two of the Kompogas technology – one since 2014, and one since 2015. Unfortunately, due to very low biowaste separate collection levels, majority of the recently constructed plants have been designed as a part of mechanical-biological treatment (MBT) plants and process so called organic fraction of municipal solid waste (OFMSW) which was mechanically separated from residual waste. One large AD plant (based on the Eggersman technology) for source separated biowaste is currently under construction in the city of Poznań.

The experiences from the first AD plants for OFMSW are collected and evaluated in order to find the optimal function modus. It is envisaged that the biological part of the existing MBT plants in Poland should gradually be turned into installations treating source separated biowaste. However, changing the incoming waste streams will have some technological as well as economic consequences. A properly designed and operated AD or composting plant of biodegradable waste should be self-financing or even bring some economic revenues for the plant operator. A stable legal and market situation, including a justified level of support for renewable energy sources, is needed to establish a well-functioning cooperation with other entities who are recipients of the electricity and heat from the AD process or fertilizer produced at a right price, which will guarantee the economic feasibility of plant operation.

The investment and operation costs of the AD technology vary with the level of complexity of the plant and the required pre-treatment technology, which in turn depends on the type of waste to be processed. The treatment of the OFMSW requires high level pre-treatment, which increases the initial investment. Moreover, the type of technology – whether it is dry or wet process and the plant capacity influences the investment costs. According to [8], the investment costs of dry AD with limited pre-treatment (accepting only source separated biowaste) is within the range of 200–450 $/t of annual processing capacity. The investment costs of dry AD with more advanced pre-treatment (accepting residual waste) amounts to 450–530 $/t and of wet AD with advanced pre-treatment in the range of 450–600 $/t, both related to 1 t of annual processing capacity. The authors [8] report that the operation and maintenance cost of AD only (thus without pre-treatment) are in the range of 20–35 $/t. The influence of the economy of scale is quite significant, as can be demonstrated by the investment costs of the Dranco technology of dry AD. The range of investment costs amounts from 1.800 to 250 €/t of annual capacity, respectively, for the plants with capacity from 5 to 100 thousand t/year [9]. Thus the investment costs for the plant of this technology amount to 15, 19 and 25 Mio €, respectively for installations with the capacity of 25, 50 and 100 thousand t/year. According to [7], the operational costs for the treatment of OFMSW in five various AD technologies (Dranco, Kompogas, Valorga, BTA and Waasa) in a plant with the capacity of 20 thousand t/year vary from 62–63 €/t (dry AD in the Dranco and Kompogas) to 90–95 €/t (wet AD in the BTA and Waasa). The operation costs of the Valorga (semi-dry process operating at 25–32% of dry matter content) amount to 68 €/t. The operating costs also depend on the plant capacity and may vary from 40 to over 150 €/t, for the capacities from 55 thousand t/year to 5 thousand t/year.

Fixed AD processing costs (taking into account the capital cost, the cost of financing and the operating cost) of biowaste/OFMSW amounted in Austria, Belgium, Denmark and France 80, 82, 67, and 57 €/t, respectively [5, 10]. In the UK, for AD plants with a capacity of 21–40 thousand t/year, the investment costs (building, maintenance and equipment) and operational costs amounted to 236.10 £/t of annual capacity and 8.64 £/t, respectively, the potential sale of electricity accounted for 2.94 £/t, and the gate fee was 64.67 £/t [5, 10].

The investment costs of the composting technology are significantly lower than those of the AD technology. In the UK, the composting plants applying the batch tunnel in-vessel composting system with the annual capacity of 20 thousand t show the total investment cost of 2.5 Mio £ and for the vertical in-vessel composting system (similar capacity) – 2.1 Mio £ [5, 10]. According to [2], the capital costs of the composting technology vary between 1 and 5 Mio £ for facilities with a capacity of 10–100 thousand t/year, while the operating costs are estimated at 20–30 £/t.

2. OBJECTIVES AND THE METHODS

The aim of the study was to analyze alternative concepts of improving the efficiency of energy and product recovery of biodegradable waste coming from the rural area in Poland. As mentioned above, since the separate biowaste collection in Poland is at a very low level, the prevailing technology is to stabilize the OFMSW mechanically separated from residual waste, with subsequent landfilling of the so called stabilate. This can be done either in the aerobic digestion process or in a much more common aerobic stabilization process. The AD scores better in environmental terms, however the investment costs are much higher than for the aerobic stabilization. The processing of OFMSW causes many operational problems and, moreover, the applications of the generated output are very limited. Therefore it is generally necessary to introduce separate collection of biowaste and gradually turn the current MBT plants into biowaste treatment plants. In the transitional period, when the amount of separately collected municipal biowaste is not high enough to feed the plant, other streams of biowaste such as industrial and agricultural biowaste could be co-processed. In this paper, the economic analyses of treating the mechanically separated biofraction of residual waste and of alternative waste streams has been performed. The main focus is on the assessment of the profitability of the anaerobic digestion technology using different waste streams and under various market conditions. In the final part, the outputs of this analysis were compared with the profitability of aerobic stabilization of the analogical waste streams and under the same market conditions.

The analyses were based on available data from literature and from the already operated dry AD plants in Poland. The analyses were performed for the plant equipped with two separate digesters, each of them with a total capacity of 23 thousand t/year, assuming a two-week retention period in the chamber. The anaerobic step is followed by aerobic stabilization in an enclosed reactors. The plant applies dry, thermophilic method allowing the processing of mechanically separated biodegradable fraction of mixed municipal solid waste (0–60 mm) into biogas.

On the basis of the municipal waste generation prognosis, in the region which is served by the plant, the streams of mixed municipal waste and separately collected biowaste have been estimated. Initially two digesters were fed with OFMSW, but in the future it is proposed to feed only one of the digesters with the OFMSW and the other chamber with source-separated biowaste. The respective input quantities amount to 9304 t/year of the OFMSW, 2 thousand t/year of wood chips (the co-substrate enabling more efficient separation of water from the digestion residue), as well as 11 946 t/year of fresh water mixed with digestion effluent. The energy content of biogas predicted to be generated from the first chamber amounts to 22 319 GJ/year. The second digester would be fed with the separately collected kitchen and garden biowaste (2218 t/year) as well as biowaste from green areas (1549 t/year) and 2 thousand t/year of wood chips. This wouldn't be enough to feed the chamber of this size. To increase the waste stream (and thus also the yield of biogas) it is proposed to acquire additional biowaste from industrial and agricultural sources that would be suitable for the dry AD process.

This study analyzed two alternative sources of industrial and agricultural wastes to fill the second digester. In the first option the feeding of 11 278 t/year of industrial wastes into the digester was assumed to reach the required level of dry matter (35%, after adding fresh water and/or leachate) as well as an appropriate carbon to nitrogen ratio (20–30). The waste would be acquired from two sites located at a distance of 12 km and 35 km from the plant. Thus in total ca. 17 thousand t/year is fed to the second chamber. These wastes when mixed together will be characterized by 42% of dry matter content and the carbon to nitrogen ratio of 23. By introducing a stream of industrial waste to one of the digesters along with selectively collected municipal waste, wood and fresh water and leachate from the AD process (in appropriate proportions), it will be possible to generate biogas with the energy content of 35 125 GJ/year. The digestate originating from the AD process can be used as fertilizer.

3. RESULTS

Table 1 summarizes the characteristics of the OFMWS (first chamber) and biowaste streams (second chamber) led to the AD process in case of selecting the first option. Industrial waste with highest energy content were selected for this option from industrial facilities located close to the AD plant. Calculations are based on [11–13].

The second option assumes the acquisition of 6729 t/year of industrial waste, only from the close located industry (12 km from the digestion plant), which will reduce its transportation needs and make the logistics easier. This waste when mixed together with the remaining biowaste are characterized by slightly higher content of dry matter and the carbon to nitrogen ratio than in the first case. The maximum yield of energy from biogas which can be achieved from the specified industrial waste stream amounts to 15 541 GJ/year. To achieve the optimal performance (and C to N ratio) and largest possible amount of energy from the biogas (while maintaining an adequate level of dry matter in the chamber of ca. 35%), it was proposed to complete the feed with 2525 t/year of agricultural waste in the form of potato haulms. Table 2 (calculations based on [11–15]) shows the characteristics of the waste stream which is fed to the digester in the second case. Finally, by introducing the stream of agricultural waste along with other substrates to a second digester it is possible to obtain a maximum energy recovery yield of 24 618 GJ/year.

Table 1

Characteristics of waste streams fed to the digester in the first option

Digestion chamber	Waste streams	Total weight [t/year]	C/N ratio	Energy content of the biogas[a] [GJ/year]
1	OFMSW	11 304	30	22 319
2	Industrial biowaste types:			
	Plant-tissue waste (sugar processing)	1845	17	7042
	Sludges from washing, cleaning, peeling, centrifuging and separation (potato processing)	6580	24	15 048
	Sludges from on-site effluent treatment potato processing)	2781	23	6360
	Waste not otherwise specified (potato processing)	72	16	316
		sum 11 278	average 23	sum 28 767
	Separately collected municipal biowaste	2218	36	3981
	Green waste	1540	46	2377
	Total	15 036	27	35 125

[a]The energy content of methane assumed at 35 897 kJ/m^3.

Table 2

Characteristics of waste streams fed to the digester in the second option

Digestion chamber	Waste streams	Total weight [t/year]	C/N ratio	Energy content of the biogas[a] [GJ/year]
1	OFMSW	11 304	25	22 319
2	Industrial biowaste types:			
	Sludges from washing, cleaning, peeling, centrifuging and separation (from potato processing)	6580	24	15 048
	Sludges from on-site effluent treatment (from potato processing)	77	22	176
	Wastes not otherwise specified (from potato processing)	72	13	316
		sum 6729	average 24	sum 15 541
	Separately collected municipal	2218	36	3981
	Green waste	1540	46	2377
	Potato haulms	2525	25	1719
	Total	13 012	29	24 618

[a]The energy content of methane assumed at 35 897 kJ/m^3.

Table 3

Assumptions used in the economic assessment of dry AD technology

Item	Anaerobic digestion	Aerobic stabilization
Energy consumption by the process	112 kWh/t of OFMSW processed 75 kWh/t of biowaste processed	20 kWh/t of waste processed
Consumption of heat of the digestion process	324 MJ/t of waste processed	–
Efficiency of electricity/heat generation from biogas by the cogeneration units	35% for electricity/50% for heat	–
Price/revenue ranges for electricity purchasing and sales	58.70–96.40 €/MWh	58.70–96.40 €/MWh
Revenue ranges for heat sales	9.20–23.85 €/GJ	–
Revenue ranges for green certificates sales	23.60–54.00 €/MWh	–
Number of people working full time	8 people	4 people
The average monthly gross salary	825.00 €/person	
Costs of water for the process	0.77 €/m^3	
Costs of wastewater discharge into the sewerage system	4.70 €/m^3	
The environmental fee for landfilling of aerobically stabilised digestate	5.65 €/t	
Costs of operation of the landfill	23.60 €/t	
Revenues from sales of fertilizer from separately collected biowaste	0 €/t	
Gate fee for residual municipal waste at the plant	73.75 €/t	
Gate fee for the separately collected kitchen and garden waste at the plant	41.20 €/t	
Gate fee for the green waste at the plant	41.20 €/t	
Costs of additional materials for the AD process	3.53 €/t waste input	–
Gate fee for the industrial waste at the plant	0 €/t (the plant will not charge gate fees for industrial waste originating, the industry in turn delivers them for free)	
Gate fee for the agricultural waste at the plant	0 €/t (the plant will not charge gate fees for agricultural waste, the farmers who deliver 1 t of potato haulm will be offered 2 t of the fertiliser produced by AD of separately collected biowaste)	
Maintenance costs of the AD installation	236 thousand €/year for two chambers (due to more harsh conditions of residual municipal waste treatment than costs for this chamber was assumed at 141 thousand €/year)	85 thousand €/year
Cost of insurances and taxes	2.36 €/t waste	0.40 €/t waste
The cost of investment and financing	31.10 €/t waste	3.18 €/t waste
Sources of data: [16–20]		

Providing appropriate conditions in the digesters, the amount of biogas to be obtained from each unit was calculated.

The basic categories of costs associated with the implementation of the dry anaerobic digestion process according to the two presented options were defined. An economic analysis for both options was done, taking into account the actual market conditions and estimated cost-effectiveness of implementing this type of investment compared to the aerobic stabilization/composting process.

Table 3 provides assumptions, costs categories and prices, which have been considered in the economic analyses, separately for the AD and the aerobic stabilization. Table 4 shows different market situations for the sensitivity analyses of the economic profitability analysis of dry AD and the composting process.

Table 4

Characteristics of the market conditions assumed for the sensitivity analysis of the economic assessment

The market condition	Sales
1	All produced electricity and heat and green certificates of origin at the lowest price
2	All produced electricity and heat at the lowest price and the green certificates at the highest price
3	All produced electricity and heat at the highest price and green certificates of origin at lowest price
4	All produced electricity and heat and the green certificates of origin at the highest price

Assuming the first of the proposed options, the installation will be able to produce biogas with the energy content up to 57 444 GJ/year, while in the case of selecting the second option the energy production will reach up to 46 937 GJ/year. In terms of the amount of energy produced from waste, the second option will be less cost effective as compared to the first one. In calculating final energy production, a 35% efficiency of electricity production and 50% of heat production in the cogeneration unit were assumed. Moreover, it was assumed that a part of this energy will be used for the own needs of the plant (75 kWh_{el} for biowaste and 112 kWh_{el} in the case of the treatment of OFMSW and 90 kWh_{th}/t waste input). Figure 1 shows the final net energy and heat production in both operating options, after own needs of the plant were satisfied. Basically option 1 allows one to achieve higher net energy yield.

Figure 2 shows the results of the economic viability analyses of implementing the dry digestion technology for both options in different market situations (Table 4). The negative values indicate the net loss, while the positive ones indicate that the process will generate a net profit. The data analyses show that under each market conditions selecting the first option of the anaerobic digestion process will be more favorable than the latter. The reason for it is that the industrial waste applied for option 1 showed a higher energy content than the agricultural waste. However, only under the market conditions 3 (electricity and heat sales at the maximum price, certificate of origin at the lowest price) and 4 (electricity and heat sales, as well as green certificate sales at the maximum price) the net profit for options 1 an 2 will be generated. Market conditions 1 and 2 inevitably lead to the net loss.

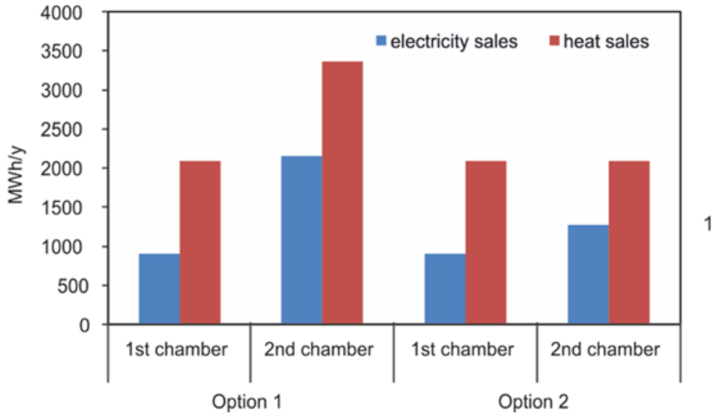

Fig. 1. Two options in terms of energy yield from waste (own calculations):
1st chamber – residual waste, 2nd chamber – bio- and industrial waste

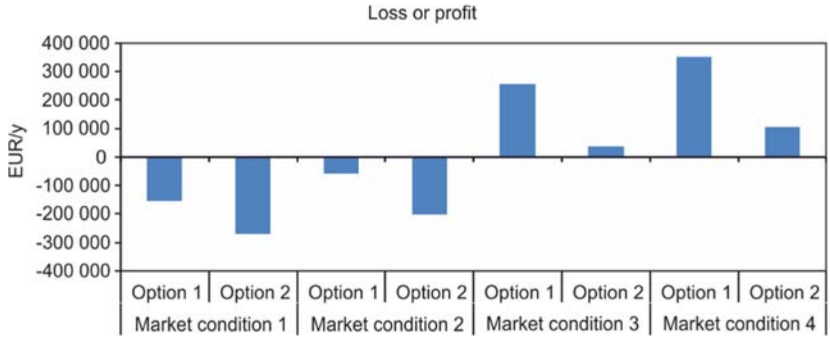

Fig. 2. Analysis of the economic viability of implementing the dry AD technology for both options in various market situations (calculations based on [16–20])

Under the current legal and economic circumstances, assuming the sales of all produced electricity and heat at the highest prices (96.40 €/kWh for electricity and 23.85 €/GJ for heat) would allow to make a profit of ca. 180 thousand €/year for option 1 of the plant operation. Additionally sales of green certificates of origin allow one to increase this profit to 252 thousand €/year and 345 thousand €/year, respectively, in the case of the lowest and highest prices for the certificates. For option 2, the sales of green certificates decide about the total profit. Without the green certificate sales, the plant would make a loss of ca. 15 thousand €/year even selling the energy at the highest prices. Moreover in all cases sales of heat are necessary to maintain the profitability of the plant. In many locations, this can be a problem because of lack of the possibility to sell heat. Selling the electricity and heat at the lowest prices (58.70 €/kWh for electricity and 9.20 €/GJ for heat) would generate a net loss, even if the plant would be selling green certificates at the highest price (market conditions 2). In this situation, the plant would have a serious problem with maintaining the operation of installation. Selling electricity and green certificates at the highest price and selling heat at the lowest price would allow one to make profit in the case of option 1 of plant operation. The same conditions for option 2 would generate the net loss.

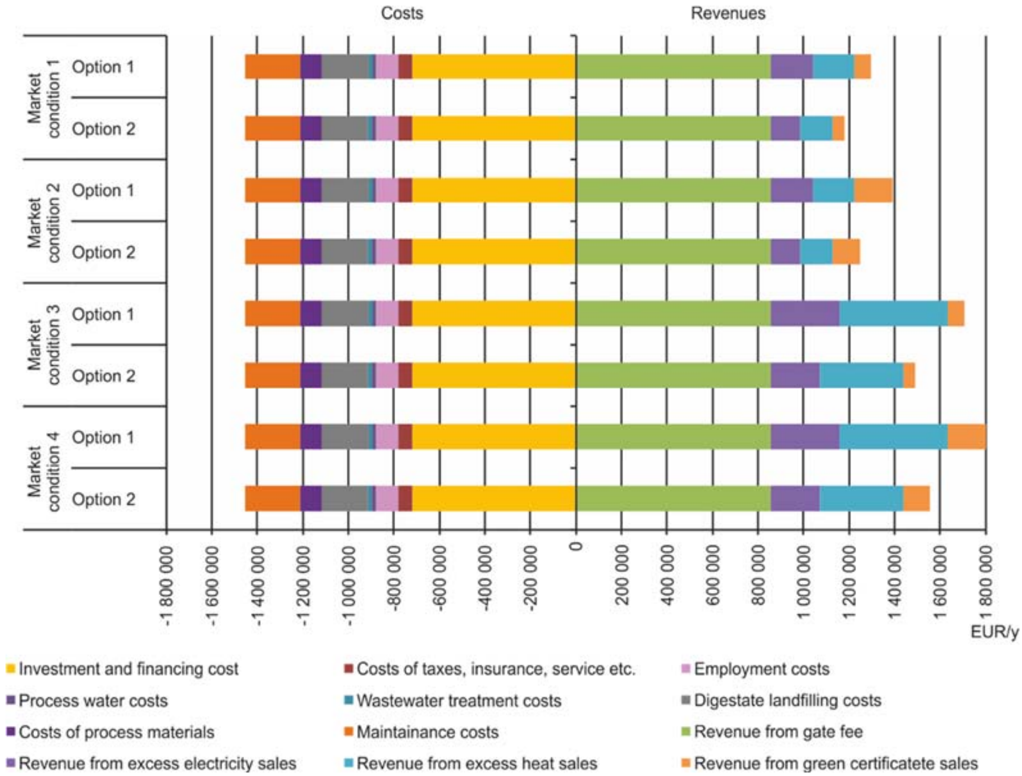

Fig. 3. Costs and revenues of the dry AD process under four market conditions (calculations based on data provided in Table 3)

Figure 3 indicates the shares of various cost and revenues positions for both options and four market conditions. Among the costs, the highest share can be attributed to the investment and financing costs (ca. 50% of all costs). On the revenues side, the major position is the revenue from gate fee for accepting waste to the plant. It should be noted that the revenues were only assumed for the municipal waste (residual waste and biowaste). Varying revenues from energy sales decide about the final loss or profit of the installation. The contribution of revenue from heat sales is very important. It is rather unlikely that the installation would be able to sell heat at the highest market price. In this case only option 1 of plant operation is likely to generate long term profit (if the electricity and green certificate prices are favorable).

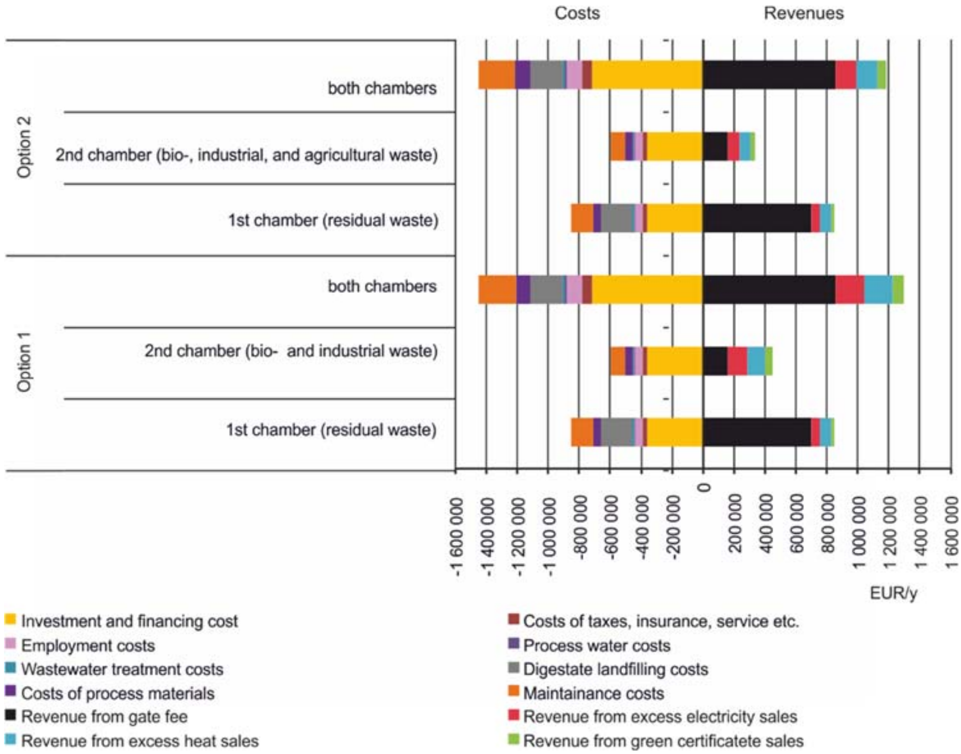

Fig. 4. Costs/revenues levels of individual chambers for both options of AD under market conditions 1 (calculations based on data provided in Table 3)

Figures 4 and 5 present results in terms of costs and residues separately for each digestion chamber. It shows that it is more economically viable to conduct a dry AD of OFMSW rather than running the AD of separately collected biowaste (including biowaste from industry/agriculture). It is because of the significantly higher contribution to the total revenue of the gate fee, which is much higher for residual waste than for separately collected biowaste. Even if the maximum prices for electricity, heat and green certificates the contribution of the gate fee for the residual waste treatment amount to 69% of the total revenue, while in the case of biowaste it is in the range of 20–29% only. This is due to generally lower gate fee for the municipal biowaste and the assumption that both the industrial biowaste and agricultural biowaste will be accepted at a zero cost. The reason for it is that there is a competitive demand for this kind of waste, generated by the agricultural AD plants. The agricultural AD plants often process biomass, which the need to buy (e.g., energy crops) and thus they are eager to acquire waste biomass at least at zero cost, thus standing in competition to municipal AD plants, for which a gate fee is one of the major revenues for waste treatment.

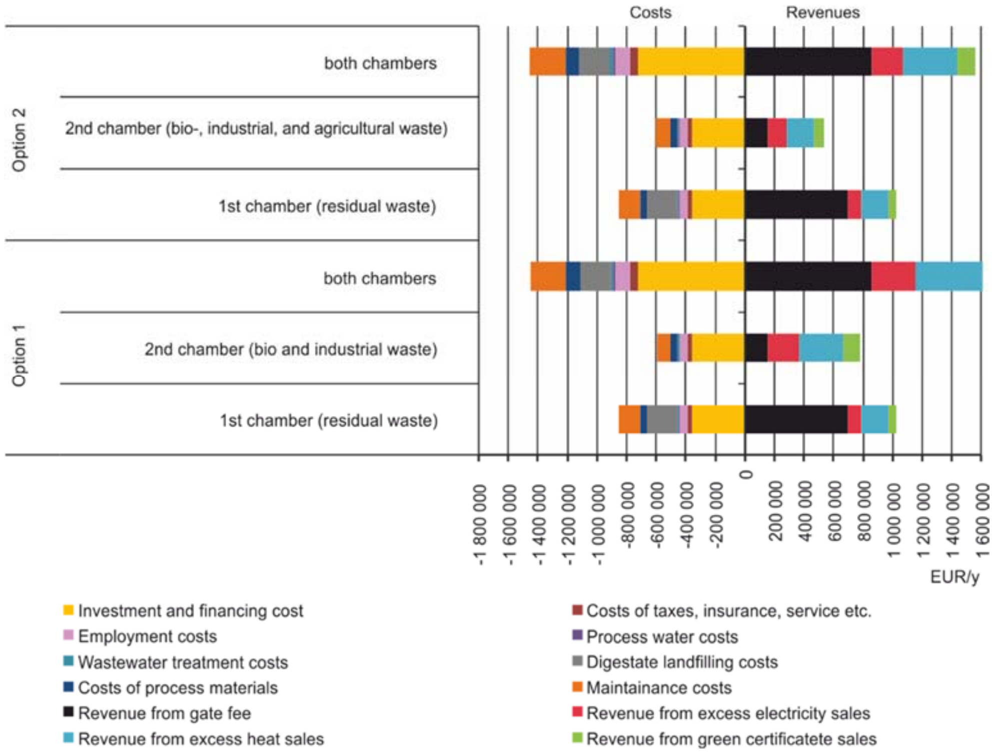

Fig. 5. Costs/revenues levels of individual chambers for both options of AD under market conditions 4 (calculations based on data provided in Table 3)

In order to assess the economic viability of implementing dry AD process, it was compared to aerobic stabilization/composting, as the most common technology for bio-waste treatment. The same input streams were assumed for all processes (both for option 1 and option 2). The loss of mass during aerobic stabilization was assumed to be 22% related to the initial mass.

Figure 6 shows the results of the economic analysis of aerobic stabilization and anaerobic digestion based on the market situations 2 (the lowest energy prices) and 4 (the highest energy prices). The results show that regardless of the electricity prices, the aerobic stabilization generates profit. The first option scores slightly better. The profit generated by the anaerobic digestion can be significantly higher for option 1 under market condition 4. However already for option 2 under this circumstances the level of profit is similar to the one generated by the aerobic stabilization process. Basically the aerobic stabilization generates profit under all conditions and is not too much influenced by the change of market conditions.

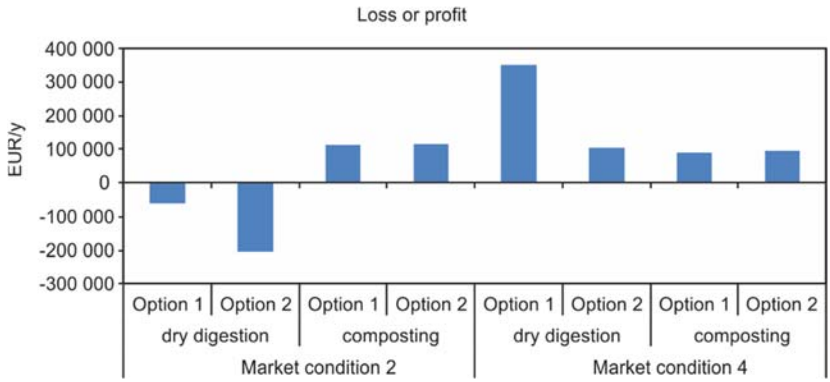

Fig. 6. Economic analysis of the profitability of anaerobic digestion and aerobic stabilization for both input options under market conditions 2 and 4 (calculations based on data provided in Table 3)

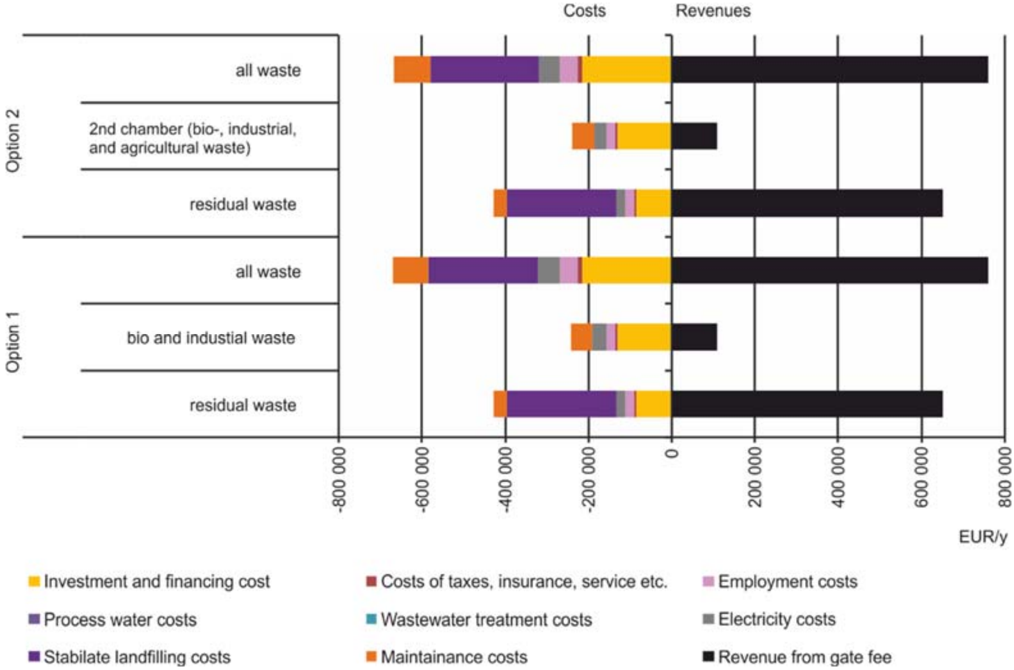

Fig. 7. Costs and revenue levels for composting process for two options of waste composition and the market situation assuming the highest energy costs (calculations based on data provided in Table 3)

Figure 7 shows the costs and revenue levels for aerobic stabilization/composting for two options of waste composition and the market situation assuming highest energy costs. On the costs side, the highest costs for the residual waste are related to the landfilling of stabilate. It is however compensated by the higher revenue from the gate fee. Thus in the case of the residual waste treatment, the profit is ensured. Treatment of separately collected biowaste, industrial and agricultural biowaste does not generate the landfilling costs, because the generated fertilizer can be utilized. On the costs s, it was assumed that the distribution of fertilizer would be for free, so it does not bring any revenue. The revenues from gate fee are only acquired if municipal biowaste is treated, while industrial and agricultural biowaste (as in the case of digestion) would be accepted for free. Then the total revenue is too low to cover the plant costs and the plant operated only with biowaste from these sources would generate loss. This means that the plant would need to introduce gate fee for the industrial and agricultural waste to be able to finance its costs.

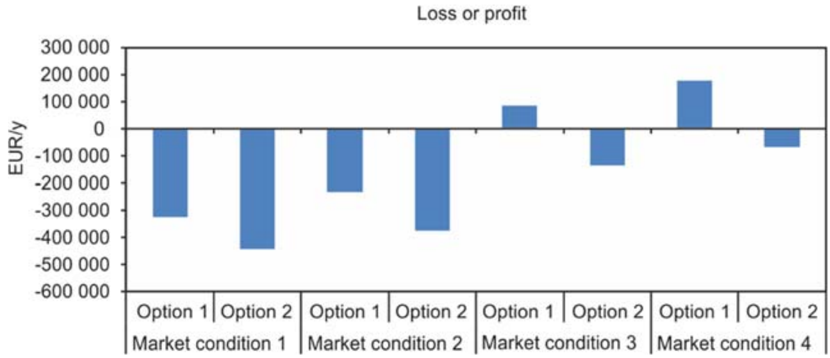

Fig. 8. Sensitivity analysis of the economic viability of implementing the dry AD technology for both options in various market situations, assuming lower gate fees

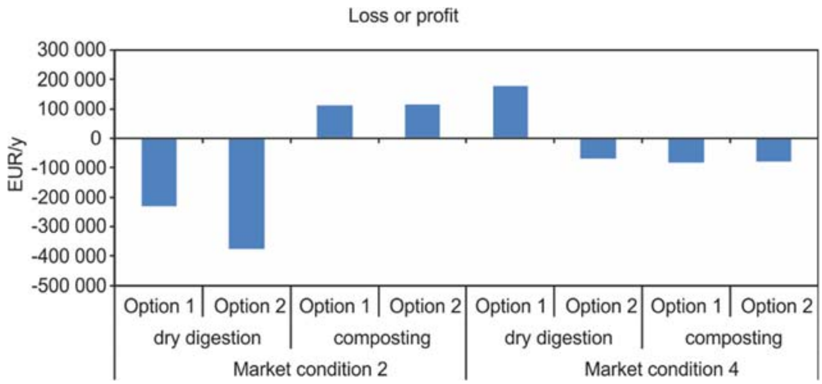

Fig. 9. Sensitivity analysis of the economic profitability of dry AD and aerobic stabilization processes with lower gate fees, for both input options under market conditions 2 and 4

Gate fees assumed in this study are the actual ones for the exemplary plant which was considered here, however in the region where this plant is located the price level is generally higher than the average for Poland. Therefore the last sensitivity analysis was performed assuming lower gate fees – 59 €/t for accepting residual waste and 33 €/t for biowaste. This clearly undermines the economic feasibility, which is shown in Fig. 8 (cf. Fig. 2). In this situation only option 1 generates profit under market conditions 3 and 4.

Similarly, Figure 9 shows the results of the economic analysis of aerobic stabilization and anaerobic digestion with the lower gate fees, based on the market situations 2 (the lowest energy prices) and 4 (the highest energy prices). As opposed to the previous results (Fig. 6), it can be seen that under market conditions 4, both aerobic stabilization and anaerobic digestion/option 2 generate loss. Only anaerobic digestion/option 1 can generate profit under these conditions, which is due to higher energy production and higher revenue from energy and green certificates sales, than in all other circumstances. In case of high energy prices, the aerobic process, which only consumes energy is obviously less favorable. It also means that the to cover all the expenses of the considered stabilization technology the gate fee must be higher.

4. DISCUSSION

From an environmental point of view, the properly functioning biogas plants generating energy from renewable energy sources have a significant advantage over aerobic stabilization/composting of biodegradable waste [21]. However, the results of the economic analysis of anaerobic digestion and aerobic stabilization show that the profitability of both processes to a large extent depends on the situation on the energy market. Under the current legal and market circumstances, the sale of generated electricity and heat from dry AD process, as well as the green certificates at the highest price would ensure high profitability. However, already the lack of possibility to sell heat, or selling it at the lowest market price results in the overall loss. Also selling both the electricity and heat at the lowest price and the green certificates at the highest price does not ensure continuity of the operation (too low profit to make up for the high investment cost).

In view of the fact that in Poland electricity and heat from biogas does not have market preferences, the biogas plants have to compete with more efficient RES technologies, AD is surely not the most save option of residual and biowaste treatment. In the case of residual waste treatment, some part of revenue loss can be compensated by the higher gate fee. It is rather unlikely to obtain higher gate fee for separately collected biowaste as well as industrial and agricultural biowaste. In this paper, the same technology and investment costs were applied for different waste inputs. It was assumed that the AD plants and aerobic stabilization plants for residual waste will be in the future transformed into biowaste treatment plants. This would happen when the level of separate biowaste collection increases is high enough to feed these plants. However, this causes a problem of too high fixed costs, resulting from initial investment costs in the technology originally suited for the residual waste, which requires a significantly higher pre-treatment level than biowaste. This is especially true is the case of digestion technology. The plants for residual waste treatment require sophisticated equipment for the mechanical pretreatment (removal of inorganic contaminants and fines), which would not be needed for biowaste. As a result, the costs of biowaste treatment in these plants are too high for the market conditions and they cannot compete with much simpler installations which were originally designed for biowaste.

To make the operation of digestion plants economically feasible, higher support for this technology would be needed. Ensuring higher prices for green certificates confirming RES originating from municipal biogas plants could be one solution. Analysis of the situation in other countries such as Germany or Austria shows that in these countries there exists substantial financial support for electricity from biogas utilities. For example, German law provides biogas plants processing municipal biowaste from urban with support at the level of 110 €/MWh (for the plants with installed capacity >500 kW_{el} which are commenced by 2020) up to 150 €/MWh (for smaller installations which were commenced by 2012 [22]. Existing of high support for the biogas plants resulted in the increase of the number of dry AD plants in Europe by 71% in the period 2006–2010. On the other hand, the economic viability of a technology should not rely on subsidies. Another, much more reasonable solution is that these plants should be co-located in vicinity of other industries (e.g. within industrial parks), which would ensure that all the heat generated at the digestion process could be utilized and thus generate the additional revenue.

5. CONCLUSIONS

Due to low biowaste collection levels in Poland, the majority of AD plants are functioning as a biological part of the MBT installation, processing mechanically separated OFMSW. Processing of OFMSW is accompanied by major technological problems, ranging from the operational problems to the limited use options for the generated stabilate. Therefore with the growing rates of separate biowaste collection it is possible to switch to an easier feedstock in the future. However in the transitional period the biowaste chamber would need to be completed by biowaste from other sources such as industry or agriculture. Many industrial and agricultural biowaste sources are suitable for dry AD process. The costs and revenues of AD were calculated for various waste streams. Based on the economic analysis, it was shown that within the current market conditions dry AD of OFMSW provides more economically viable option than the digestion of separately collected biowaste (including industrial and agriculture sources).

The reason for that is the higher gate fee which can be asked for the residual waste accepted to the plant than for the separately collected biowaste. Moreover, under current market conditions it is rather unsure that the plant could charge for the accepted industrial or agricultural biowaste. There exists demand for these clean organic fractions in the agricultural AD plants. In this case, the major revenue of the plant would be from excess energy sales. The yield of biogas from biowaste vary based on the biowaste source and type. In the analyzed options, directing the industrial waste to the AD process turned out more profitable than co-processing of industrial and agricultural waste. Cost-effectiveness of the AD of separately collected biowaste to a very large extent depends also on the energy market and existing support for RES. Introduction the opportunity to sell green certificates of RES origin by municipal biogas plants significantly increases profits from their activities. Also it is crucial to ensure that the generated heat is also sold and generates additional profit. This could be ensured by locating the AD plants in the industrial parks.

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