Scientific Bulletin of Politehnica University of Timişoara

Transactions on HYDROTECHNICS

Volume 61(75), Issue 2, 2016

Comparison of different treatment solutions for organic waste

Mihaela Berechet* **Martin Kranert*** **Gerold Hafner***

Abstract: Currently in Stuttgart organic waste is only partly separate collected. Since it is not valorized at its potential there are considerations to increase the coverage of separate collection and alternatives for treatment are sought.

This article aims at comparing different solution of valorization of the organic source –separated organic waste, underlining the possible CO_2 credits of each solution on a case study in Stuttgart, Germany.

Scenarios are developed and compared, considering solutions such as valorization of the organic waste in an incinerator or in biogas plant. In the case of biogas plant there are analyzed two different technologies: Kompogas and Valorga.

Keywords: organic waste, incineration, biogas, CO_2 credits

1.INTRODUCTION

Currently, in the Stuttgart area, are skimmed over the compost bin around 15.000 t/a organic waste, from which approximately 10.000 t/a are processed into compost in the composting plant Kirchheim and 5.000 t/a are recycled by a private composter. Out of the total amount of household waste in Stuttgart (which is about 110.000 t/a), around 40.000 t/a represents organic material.

There are consideration to significantly increase the currently skimmed organic waste amounts by additional container volumes and accompanying publicity. A preliminary assessment of the waste management Stuttgart (Berthold, E., Hoeß, P., 2010) estimates the additional potential levy of almost 16.000 t/a.

At the moment, the residual waste of Stuttgart, with its high percent of organic fraction is incinerated being thus used for energy production in the waste incineration plant in Stuttgart-Münster.

Organic waste can be recovered in different ways. Throughout a thermal treatment (incineration) energy is obtained, however, the potential for material utilization is not exhausted. When composting the organic waste, on the contrary, only the material potential is exploited but the potential for energy production get lost. A biogas plant combines both material and energetic use variants. The digestate can be used in agriculture either directly or after subsequent treatment steps, such as composting, if necessary.

The biogas obtained can be used to generate energy. Here again, different variants are possible, for example the direct use of biogas (as biogas burner for heat production), the recovery in a cogeneration plant (CHP) for the generation of electricity and heat, or if necessary the further purification of Biogas to natural gas quality to be fed in existing infrastructure.

Recycling of organic waste in a biogas plant with the use of digestate residues represents from ecological point of view a very good solution. The organic waste is a renewable energy source and the biogas produced from organic waste can substitute the use of fossil fuels, replacing thus greenhouse gas emissions with climate-neutral CO_2 emissions.

The energy recovery of organic matter takes place in the MVA-Münster (scenario 1). This represents the status quo, which is compared with the hypothetical alternatives for combined material and energy recovery (biogas plant in the scenarios 2 and 3).

The incinerator in Münster represents a modern plant with best available technology and relatively high energy efficiency.

For the scenarios 2 and 3, two process variants were selected for the production of biogas in the comparative examination.

Scenario 2 is based on the Kompogas process. This is also a state of technology, corresponding to a well-proven method.

Scenario 3 is based on a real plant in Freiburg, which is based on the Valorga concept.

They were chosen by the project sponsor due to their easy and efficient operation management.

In the framework of this study a comparison of these recycling alternatives is carried out, to determine which one is a better solution.

2. METHODS AND PROCEDURES

Three scenarios were developed and compared from the point of view of their ecological impact. The evaluation of the scenarios was done considering the mass and energy balances as well as the emissions of

---

[1] niversität Stuttgart, Institut für Siedlungswasserbau, Wassergüte und Abfallwirtschaft, Bandtäle 2, 70569, Stuttgart, Germany, mihaela.berechet12@googlemail.com

greenhouse gases. Below are shortly enumerated the three scenarios:

Scenario 1: Valorization of organic waste in an incinerator (Stuttgart Münster)

Szenario 2: Valorization in a hypothetical biogas plant, using the Kompogas technology

Szenario 3: Valorization in a biogas plant, using Valorga technology

The first undertaken step was to define the system that was subjected to investigation and to compile the necessary data. As part of this process the composition for two waste streams relevant for the study, namely household waste and organic waste, was modeled, taking into account the waste levy rates. For each scenario the material flow was built and the mass balances were determined. The above mentioned modeled streams were fed into the three recovery scenarios and the results were afterwards compared.

To determine the climate-relevant emissions and the preliminary assessment of the substitution of fossil CO_2, average data for the Federal Republic of Germany was used. For modeling the collection and transport process the following data was used:

Tabel 1 Diesel consume by collecting organic waste in Stuttgart - Bad Cannstatt (Landeshauptstadt Stuttgart)

Organic waste collection in Bad Cannstatt		
Plate number	Fuel	Consume (l/5 months)
S-LH 8058	Diesel	4.276,30
S-LH 8057	Diesel	12.149,64
S-LH 8229	Diesel	14.214,53
S-LH 8213 (1/week)	Diesel	6.526,34
S-2942 (1/week)	Diesel	3.231,11

In Table 2 is compiled the data used for the credits for use of liquid fertilizer and compost.

Table 2 Energy and greenhouse gas substitution (Springer, C. 2010)

	Fresh compost		Mature compost	
Nutrient	Energy [MJ /t]	CO_2 eq. [kg CO_2-eqv/t]	Energy [MJ /t]	CO_2 eqv [kg CO2-eqv/t].
N	382	39,4	322	33,2
P	168	8	134	6,4
K	146	8,6	123	7,3
Ca	100	5,7	100	5,7
Total	**796**	**61,7**	**680**	**52,6**

3. WASTE COMPOSITION AND PROPERTIES

Currently in the incinerator Münster there are each year 450.000 t residual waste incinerated and converted into electricity and district heating.This includes approximately 100.000 t/a domestic waste from the city of Stuttgart.

The following figure shows the composition of the Stuttgart household waste. The organic material represents approximately 36% of the residual waste. This corresponds to round 41.000 t of organic material per year ending up in the residual waste bin instead of the organic waste bin. The average calorific value of residual waste is in the range between 9-11 MJ/kg, while that of organic waste only 4 MJ/kg.

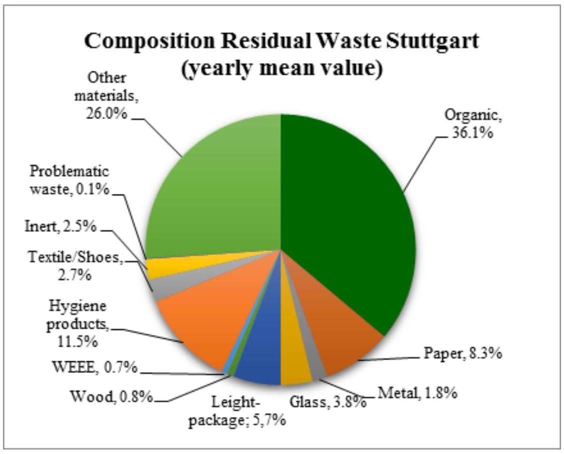

Figure 1. Composition of residual waste in Stuttgart, based on data (Berthold, E., Hoeß, P., 2010)

In the Stuttgart area in addition 15.582 t/a organic material is collected via the organic waste bin. The main components are the organic fraction contained in the medium and fine waste with 36,8% and the herbaceous garden waste with 33,3%. The non cooked kitchen waste represents 14,3%. The composition of the waste disposed in the organic bin is shown in the following figure.

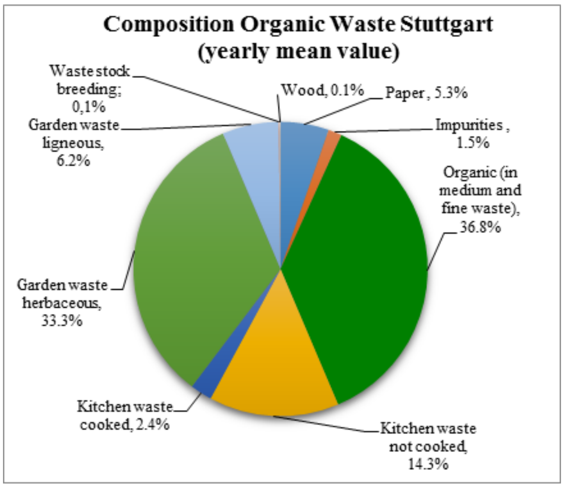

Figure 2. Composition of organic waste, based on data (Berthold, E., Hoeß, P., 2010)

In the scenarios was considered only the separate collected organic waste. Still it was kept in mind also the high potential of additional quantities to be skimmed from the residual waste bin.

4. SCENARIO 1 - INCINERATION

In the waste incinerator Münster it is incinerated the residual waste from the city of

Stuttgart and some of its surrounding communities, being converted into electricity and district heating.

The system boundary is shown in the following figure.

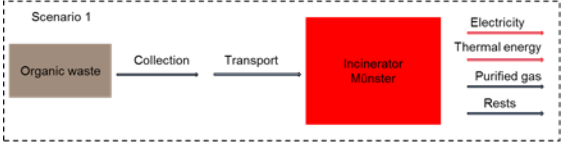

Figure 3 System boundaries for incineration scenario

The treatment process comprises the following steps: reception (waste bunker), crushing, incineration (waste tank) and flue gas cleaning.

The thermal efficiency of the plant is 43,3% and the electrical efficiency 16,5%. Larger losses occur in areas such as complex flue gas cleaning, that consists of a dust collector, a wet scrubber and a catalyst.

In the flue gas cleaning system, the flue gas, freed from dust, passes through a four-stage wet scrubbing with caustic soda, where hydrogen chloride, hydrogen fluoride, sulfur dioxide, heavy metals, aerosols and particulate matter can be substantially removed. The addition of a small amount of activated carbon causes dioxin removal and a quicksilver binding. The washed-out pollutants are removed as dry salts and disposed of. In catalyst it is the carried denitrification and the oxidative destruction of the remaining residual organic constituents, in particular dioxins and furans.

As combustion residue results slag, that is cooled in a water bath and then is transported by conveyor belts to the slag bunker. From there, the slag is taken for valorization. Also the flue dust and the salt from the flue gas scrubber are utilized.

The heat released during the combustion gives off its energy to a water-steam circuit. The water flows through a several-kilometer pipe system in the tank. The resulting steam is directed at a pressure of 60 bar and a temperature of 500 C° over a turbine and used to generate electricity and district heat. In the following figure is the scheme of the incinerator in Münster.

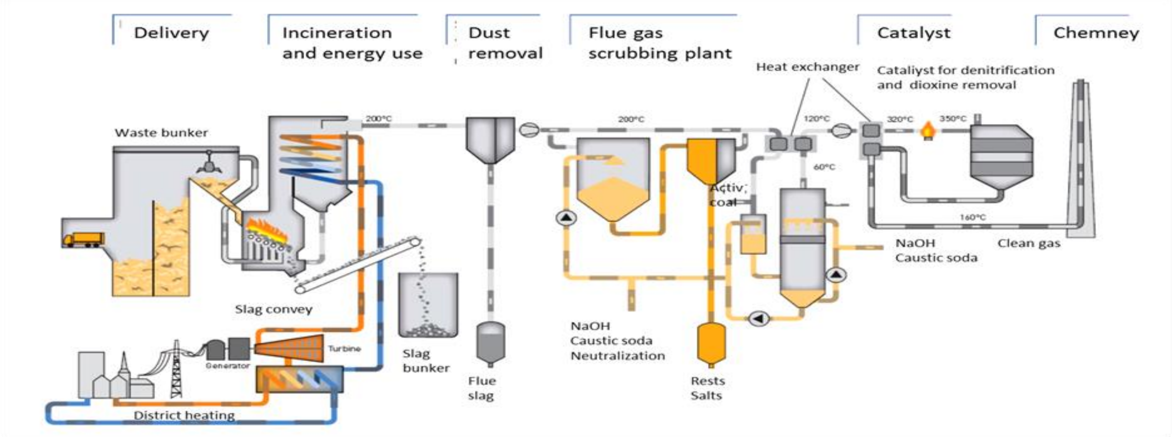

Figure 4. Scheme of incinerator Münster

In the following table is summarized the input and output of the incinerator, related to the separate collected organic waste.

Table 3. Mass balance for incinerator

Input		Output	
Material	Mass flow [t/a]	Material	Mass flow [t/a]
Organic	15.582	Moist flue gas	121.527
Combustion air	103.620	Moist ash	3.272
Caustic soda	171	Filter dust	561
Ammonia	8	Salts	134
Active coal	2	Iron scrap	327
Brine for exchange resins	18		
Softened water for scrubbing	4.706		
Water for gas scrubbing	1.075		
Water for ash bath	545		
Natural gas	94		

Assuming the co-incineration of 15.582 tons of organic waste per year in the incinerator Münster and a theoretical calorific value for organic waste of 4 MJ/kg result an annual CO_2 credit of 3.348 t CO_2 compared to electricity and heat mix from Germany. The common transport of organic waste with the residual waste is neglected in the balance sheet, since it has no decisive influence on the credit. The reference and production values are summarized in Table 4.

Table 4. Reference values and production values

Mass organic waste	15.582 t/a
Calorific value organic waste	4 MJ/kg
Thermic efficiency	43,3 %
Electric efficiency	16,5 %
Produced energie	17.313 MWh/a
Thermic energie	7.497 MWh/a
Electric energie	2.857 MWh/a
CO_2 credit	3.348 t CO_2/a

5.SCENARIO 2 – BIOGAS PLANT WITH KOMPOGAS TECHNOLOGY

In Kompogas plants separately collected organic waste, leftovers and green waste can be anaerobic processed. These materials are used as substrates (raw material) for Kompogas digestion plant. The plant converts organic waste into end products in form of biogas and digestate.

Figure 5 System boundaries for Kompogas scenario

The process can be divided into the following method steps:
-delivery and preparation of the starting material
-anaerobic digestion
-post-treatment of digestate
-biogas recovery
The main component of the Kompogas plant represents the thermophilic plug flow. It ensures a very high operational reliability, defined retention time, secured sanitation, small footprint and a high specific gas yield.
Other components of the system vary in design according to customer and location needs. They can be:
-receiving area
-buffer store for continuous feeding also outside regular working hours
-processing
-input
-Kompogas fermenter
-dewatering of digestate by screw extrusion press
-settling tank for press water
-decanters for press water follow (optional)
-CHP (in biogas CHP no input of fossil fuels for firing)
-infrastructure container and plant control
After the delivery the impurities are removed and the organic waste is crushed and sieved. The biomass is moisturized with process water and mixed with already fermented material. In a heat exchanger it is brought to fermentation temperature.
The fermentation process takes place in a lying plug-flow digester for 12 to 15 days. The biogas is collected, purified, dehumidified and fed into a combined heat and power-plant. The thermal and electric energy produced, exceeding the own consumption of the plant, is fed into the district heating and the electricity network. Alternatively, the biogas can be processed into fuel and fed into the natural gas grid.
The digestate is removed from the digester and dewatered. A part of the press water remains in the process, the rest is used in agriculture as a biological liquid fertilizer. The dewatered digestate is transformed into compost under the influence of oxygen in a bunker during the post-rotting process. After one week the material is mixed with fresh compost and composted for six weeks.

Also in this scenario it is considered as input the 15.582 t organic waste separated collected. 1.244 t rainwater and process water will be added. In this scenario the water balance is neutral since no additional fresh water is introduced in the process, and no additional water leaves the process.

Table 5. Mass balance Kompogas

Input		Output	
Material	Mass flow [t/a]	Material	Mass flow [t/a]
Organic waste	15.582	Impurities	254
Rainwater/ Process water	1.244	Fluid fertilizer	9.081
		Compost	5.344
		Biogas	2.148

To determine the credit for the liquid fertilizer, it was used a study made by (Knauer, T., 2008) which describes the avoiding potential compared to the industrially produced fertilizers. The credit for the compost is calculated according to data from the study of (Kranert et. al., 2007)
In the following table is summarized the data for the Kompogas technology considering minimum and maximum values for energy efficiency and biogas yield.

Table 6.Data for biogas plant with Kompogas technology

	Minimum	Maximum
Mass	15.582 t/a	15.582 t/a
Biogas yield ø	100 Nm^3/t	140 Nm^3/t
Calorific value H_u	6 kWh/m^3	6 kWh/m^3
Thermal efficiency	40%	45%
Electric efficiency	36%	40%
Thermal consumption	15%	11%
Electric consumption	8%	4%
Biogas yield	1.558.200 Nm^3/a	2.181.480 Nm^3/a
Energy	9.037.560 kWh/a	12.652.548 kWh/a
Net electricity	2.539.243 kWh/a	4.570.637 kWh/a
Net heat	2.267.181 kWh/a	4.316.713 kWh/a
Credit electricity	+1.430 t CO_2/a	+2.573 t CO_2/a
Credit heating	+526 t CO_2/a	+1.001 t CO_2/a
Total energy credit	+1.956 t CO_2/a	+3.574 t CO_2/a
CO_2 Emission collection	-224 t CO_2/a	-224 t CO_2/a
CO_2 Credit fluid fertilizer Narema	+508 t CO_2/a	+508 t CO_2/a
CO_2 Credit compost	+281 t CO_2/a	+330 t CO_2/a
CO_2 Total credit	2.521 t CO_2/a	4.188 t CO_2/a

For the CO_2 emissions associated with collection data about diesel consumption was made available from the current organic waste collection in Stuttgart.

Considering all the relevant parameters it is expected a CO_2 credit in the range between 2.521 and 4.188 t CO_2 per year, the results being shown in the following figure.

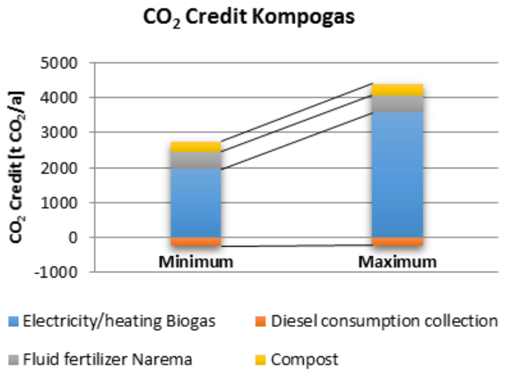

Figure 6. CO_2 credits by Kompogas plant

6.SCENARIO 3 BIOGAS PLANT WITH VALORGA TECHNOLOGY

Within a biogas plant using Valorga technology the mesophilic fermentation is carried out under anaerobic conditions at a temperature of around 37 °C. The the material remains in the tank for about 15 to 20 days.

The system boundary of the scenario 3 with the Valorga technology is presented in the figure below.

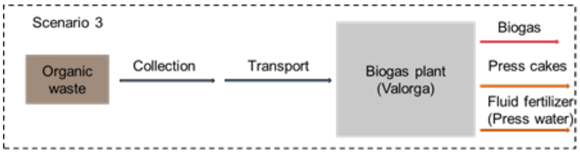

Figure 7. System boundaries for Valorga scenario

The process can be divided into the following method steps: delivery and preparation of the material, anaerobic digestion, post-treatment of digestate, and biogas recovery.

Components of the system can vary in design according to customer and location necessities: receiving area (crane, feeder), preparation (crusher, magnetic separator, drum screen, kneading mixers, pump), digester, gas tank, CHP (in biogas CHP no input of fossil fuels for firing), drainage (Screw Press), drying compost (ventilation), storage fluid phase (silo, when used as a fluid fertilizer) and air purification (acid scrubber and biofilter).

After being preheated, the material composed of processed household waste, return material and process water is fed from the top of the tank. The mixture should be homogenous and as free of air as possible. The return material and process water are carriers of bacteria. Fermentation sludge is drawn off from another point of the tanks and dewatered. The dewatered material is known as digestate and is used as fertilizer

In the digester the vertical mixing of the fermented material guarantees a constant retention time in the tank and thus a high proportion of methane and high sanitation. The semi-dry process needs almost no additional water input, since recycled process water is used. Thus it has positive effects on the overall water balance.

The anaerobic digestion leads to high methane yield and to multiple uses of the gas products. Because of the closed fermentation system the odor emissions are avoided and volatile organic intermediates directly converted into biogas. A subsequent 2-week post-rotting of the fermented material is not necessary because of operator-side optimization. The compost can be stored and sold and has a quality assured by LAGA M10 (LAGA, 1995). A magnetic separator and a drum screen ensure the purity of the end products.

Table 7. Balance for biogas plant with Valorga technology

Input		Output	
Material	Mass flow [t/a]	Material	Mass flow [t/a]
Organic waste	15.582	Impurities	250
Rainwater/ Process water	2.057	Biogas	2.353
		Fluid fertilizer	7.292
		Compost	2.524
		Wastewater	5.220

In the following table is summarized the data for the Valorga technology considering minimum and maximum values for energy efficiency and biogas yield.

Table 8. Data for biogas plant with Valorga technology

	Minimum	Maximum
Mass	15.582 t/a	15.582 t/a
Biogas yield ø	100 Nm^3/t	140 Nm^3/t
Calorific value H_u	6 kWh/m^3	6 kWh/m^3
Thermal efficiency	40%	45%
Electric efficiency	36%	40%
Thermal consumption	30%	20%
Electric consumption	15%	10%
Biogas yield	1.558.200 Nm^3/a	2.181.480 Nm^3/a
Energy	9.349.200 kWh/a	13.088.880 kWh/a
Net electricity	2.861 MWh/a	4.712 MWh/a
Net heat	2.618 MWh/a	4.712 MWh/a
Credit electricity	+1.611 t CO_2/a	+2.653 t CO_2/a
Credit heating	+607 t CO_2/a	+1.093 t CO_2/a
Total energy credit	+1.994 t CO_2/a	+3.522 t CO_2/a
CO_2 Emission collection	-224 t CO_2/a	-224 t CO_2/a
CO_2 Credit fluid fertilizer Narema	+412 t CO_2/a	+412 t CO_2/a
CO_2 Credit compost	+131 t CO_2/a	+154 t CO_2/a
CO_2 Total credit	2.537 t CO_2/a	4.087 t CO_2/a

Considering all the relevant parameters it is expected a CO_2 credit in the range between 2.537 and 4.087 t CO_2 per year; the results being shown in the following figure.

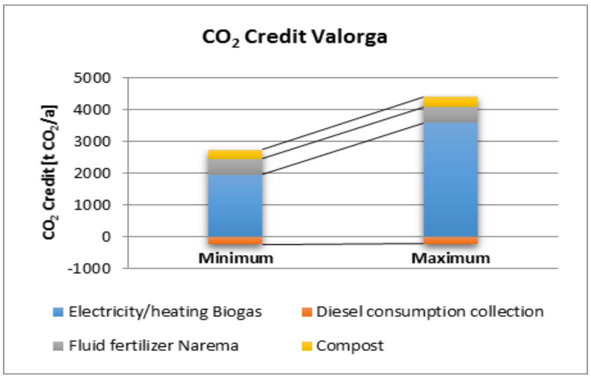

Figure 8. CO_2 credits by Valorga plant

7.RESULTS

Considering CO_2 credits of the various systems, one can notice by a direct comparison of waste incineration with the biogas production that, if the credits for by-products of the biogas plants are neglected, the biogas production has a lower overall credit than the incineration. (see Table 9).If the CO_2 credits for by-products like fertilizers are also included, the differences between the scenarios become insignificant.

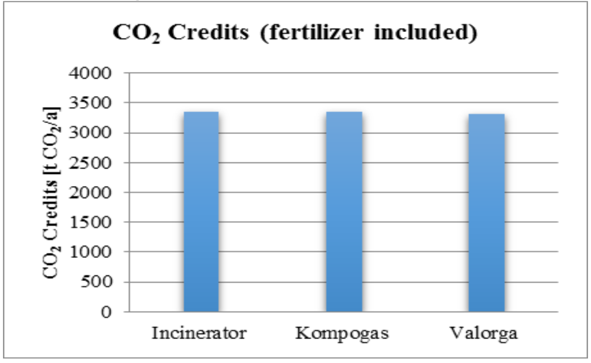

Figure 9. Comparison of scenarios considering CO_2 credits also for fertilizers

Table 9 Comparison CO_2 credits (considering the input 15.582 t organic waste/year)

	Minimum	Maximum	Mean value	
Incinerator	3.348 t CO_2/a	3.348 t CO_2/a	3.348 t CO_2/a	
Valorga	1.994 t CO_2/a	3.522 t CO_2/a	2.541 t CO_2/a	without fertilizer
Valorga	2.537 t CO_2/a	4.087 t CO_2/a	3.355 t CO_2/a	with fertilizer
Kompogas	1.731 t CO_2/a	3.351 t CO_2/a	2.758 t CO_2/a	without fertilizer
Kompogas	2.521 t CO_2/a	4.188 t CO_2/a	3.312 t CO_2/a	with fertilizer

Literature was also reviewed. Karagiannidis and Perkoulidis (Karagiannidis, A., Perkoulidis, G,. 2009) came in their study to the following results (see Table 10).

Table 10 Performances of technologies for different criteria

Process	Criteria			
	GHG emited (kg CO_2-eq/t)	Recovered energy (kWh/t)	Recovered materials (kg/t)	Operating cost (€/t)
Valorga	228	700	320	68
Kompogas	208	585	250	63

As it can be noticed the differences between technologies Kompogas and Valorga are minimal.

5.CONCLUSIONS

Both compost and liquid fertilizer add nutrient suppliers to improve the soil structure. A hygienic harmlessness of the fertilizers is, of course, obligatory to prevent outbreaks of Escherichia coli as the one from 2011 in Germany. The use of liquid fertilizers in agriculture requires appropriate logistics (tankers, pump vehicles, transport vehicles, stationary pumps, etc.) which currently are not standard equipment of the farms. Compost is very valuable for the improvement of the soil and the spreading on the fields with a compost spreader is an established process (self-mechanization of the farmers or processing by contractors). Impurities like plastics, which can cause problems, should not be present in the compost.

Good quality fertilizers (with verifiable nutrients composition, hygiene and content of heavy metal) are to be assessed as positive and necessary in the future.

Compared to compost, the current acceptance of liquid fertilizers in the agricultural sector is rather cautious, since, as mentioned, there is no or only very isolated logistics and equipment available.

Between the different treatment solutions Valorga proved the highest CO_2 credits, but the differences to the other solutions were minimal.

REFERENCES

[1] Berthold, E., Hoeß, P., 2010: Durchführung einer Hausmüllanalyse in der Landeshauptstadt Stuttgart, Im Auftrag des AWS Abfallwirtschaft Stuttgart, Endbericht

[2] Karagiannidis, A., Perkoulidis, G. 2009: A multi-criteria ranking of different technologies for the anaerobic digestion for energy recovery of the organic fraction of municipal solid wastes, Bioresource Technology, Volume 100, Issue 8, pp 2355–2360

[3]Kranert et al. 2007: Grünabfälle – besser kompostieren oder energetisch verwerten? – Vergleich unter den Aspekten der CO2-Bilanz und der Torfsubstitution. In: EdDE Dokumentation 11. Landeshauptstadt Stuttgart, 2010: Verbrauchsauswertung ASF im BIO-Mülleinsatz

[4] LAGA, 1995 Länderarbeitsgemeinschaft Abfall, Mitteilung: Merkblatt M10 über „Qualitätskriterien und Anwendungsempfehlungen für Kompost“

[5]Springer, C. 2010: Energie und CO_2 – Bilanz der Kompostierung unter Einbezug des Substitutionspotentials des Komposts, Müll und Abfall 8/10, pp. 386-396.

[6] Knauer, T. 2008: CO2-Bilanz im Vergleich mit und ohne Gärrestaufbereitung