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Ecologic, energetic and economic comparison of composting, digestion and incineration of biogenic household wastes

Summary:

In order to get more detailed information for better decision making in future biogenic waste treatment, different processes to treat biogenic wastes in plants with a treating capacitiy of 10'000 tons of organic household wastes per year were compared. The comparison included life cycle assessments as well as economic considerations for different treating methods.

Measurements on compost plants showed that methane emissions are higher than estimated so far. With the tools ECOINDICATOR and UBP anaerobic digestion shows to be advantageous as compared to composting, incineration or combination of digestion and composting, mainly because of a better energy balance.

In fully enclosed, professional treatment plants, the specific biotechnological treatment costs are in the range of about 150.-sFr/ton for aerobic, anaerobic and combined technologies. Incineration costs about double as much. It can be concluded, that anaerobic processes will become considerably more important in the future mainly for ecological reasons.

The final report will be published in early 1999.

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INTRODUCTION

Some years ago, humid biogenic wastes had been dumped or burnt in incineration plants. Today in Switzerland, the biotechnological treating methods became more important *(Schleiss, 1998)* because of legal restrictions such as TVA *(BUWAL, 1990)*, a law which favorizes separate collection of wastes and their appropriate treatment and recycling.

For the biological breakdown of biogenic wastes both aerobic and anaerobic technologies exist. The aim of this study is to compare the different treating methods from ecological, energetic and ecological points of view. So far, some comparisons have already been made (*Membrez et al. 1997, Aebersold et al. 1993, IEA 1997*). However, most of them focus on single aspects such as economy or on environmental impacts of a few parameters. The work presented in this paper tries to approach the problem in a more holistic way comparing as many parameters as possible for plants with a treating capacity of 10'000 Mg/a. Five different biotechnologies plus treatment in a modern incineration plant were examined.

ASSUMPTIONS, DEFINITION OF THE COMPARED OBJECTS

Data were sampled on existing Swiss plants. However, these installations differ in several ways: For example, the treating capacities of the plants, which were observed in this study, vary from 5'000 to 18'000 t/year. In order to get comparable data, all data were standardized: data, such as construction materials, investment costs or salaries, were calculated for plant sizes of 10'000 t/year. It was assumed that all plants were constructed in the same suburban area. This allows to assume identical transporting distances while collecting the source separated biogenic waste for all biotechnological treatment methods. It was assumed that there is no possibility to externally use the waste heat of the cogeneration of electricity and heat while producing biogas at this theoretical site. (This is a handicap for the digestion plants in comparison to incineration, where some waste heat was assumed to be sold).

The compared plants mainly differ in a.) process technology, b.) construction costs (money, energy and environmental factors) and c.) running costs including energy and emissions. The following process technologies have been compared:

- **EC**: fully **E**nclosed and automated **C**omposting plant with waste air treatment in a biofilter: The data were derived from a fully enclosed channel composting plant (IPS) with a compost biofilter,
- **OC**: **O**pen **C**omposting in boxes covered by a roof and in open windrows: COMPAQ-Boxes protected against rainfall followed by composting in open, low windrows reversed frequently and covered by gas permeable textile sheets,
- **DP**: fully enclosed thermophilic one step plug flow **D**igestion (horizontal KOMPOGAS-digester) with aerobic **P**ost-treatment in an enclosed building equipped with compost biofilters,
- **DE**: combination of thermophilic **D**igestion combined with fully **E**nclosed, automated composting in boxes (BRV-technology), where 40% of the raw material was digested before the addition to the compost line. The air is cleaned by bio-washers.
- **DO**: combination of multiple stage, thermophilic batch **D**igestion (ROMOPUR-technology) combined with **O**pen windrow composting where 60% of the raw material was digested before the addition to the compost line,
- **IS**: Incineration in a modern incineration plant including **S**crubbing of the exhaust gas streams.

For the waste incineration, a plant with a treating capacity of 100'000 t/a of mixed wastes was calculated, which increases the transporting distances to a certain extent as compared to biotechnological methods. For all plants the same waste composition was assumed (60% material relatively rich in kitchenwastes from public collection and 40% material rich in lignin derivied from private suppliers). Detailled elementary analyses of the waste are given in *Edelmann, Schleiss (1999)*.

As shown in figure 1, it was assumed that all the biotechnological treatment technologies are capable to cause a 50% loss of the organic matter (OS) by biological activities. The emissions, which were measured or taken from data bases, were distributed according to the assumptions of figure 1 and to the percentage of material treated by aerobic and anaerobic ways (see above).

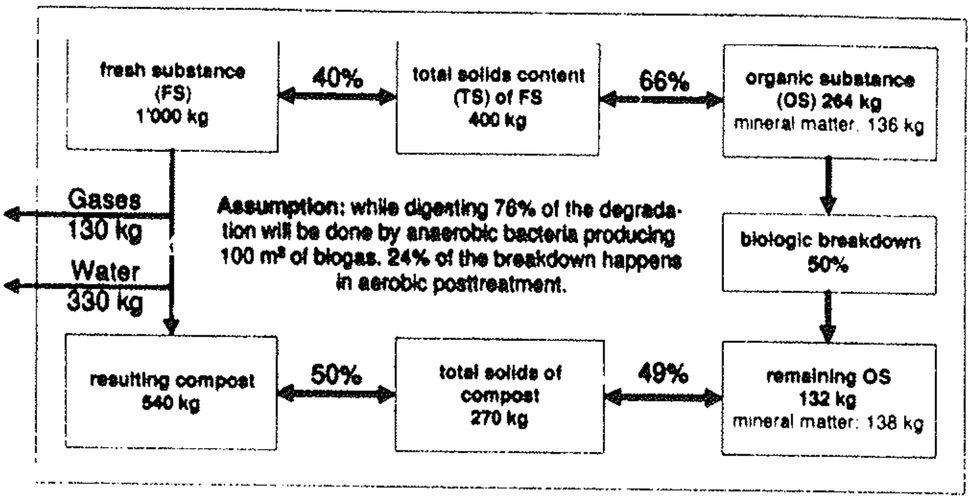


Figure 1: *Assumptions for mass fluxes while degrading biogenic wastes biotechnologically*

All data refer to 10'000 tons of fresh substance of biogenic waste. It was assumed that 1% of the waste was undesired (eg. glass, metal, plastic) and had to be burnt in an incineration plant. The whole life cycle of the biogenic wastes was compared including all environmental impacts caused by the different treating methods as well as those while producing goods necessary for the specific treatment. The assessment starts at the moment when the waste leaves the household, and includes all steps to the final application on the field (compost) or to the storing in a landfil (ashes of incineration).

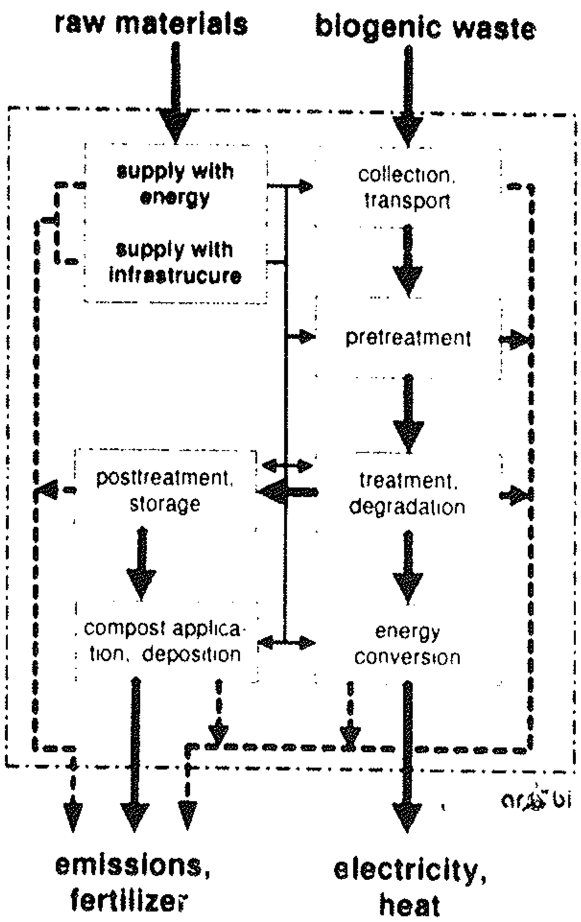
Figure 2:

Definition of the borders of the observed systems: grey, thick arrows: mass and energy fluxes entering and leaving the system; dotted black arrows: emissions; black arrows: internal connections.

There are external additions to the system e.g. material and energy necessary for the construction of the plant (infrastructure). The conversion of the renewable energy freed while degrading biogenic matter still is within the system borders (e.g. emissions of the motor burning the biogas).

The emissions while applicating the compost on the field are integrated into the consideration as well as the emissions while storing the ashes of incineration in a landfil.

Credits were taken into account for the benefits of the renewable energy and of the fertilizing substances within the compost.



Energy plays a very important role while treating biogenic wastes. It was calculated with the European electricty mixture (UCPTE) for the electricity needs of the processes as far as electricity had to be bought externally (*Frischknecht, 1996*). It was assumed that the fully enclosed biotechnological plants can be run without an excess of process water. (The biologically generated compost heat is significantly higher than the heat needed to evaporate the water in fig.1). Anaerobic plants generally have no problems with surplus water today. However, while composting in open windrows which are exposed to the rain, the production of leachate had to be taken into account.

MATERIALS AND METHODS

Eco-Inventary

All data refer to the same functional unit, i.e. to 10'000 tons of biogenic waste. A description of each process included the evaluation of the infrastructural needs, such as buildings, asphalted surfaces, machines, infrastructure for pre- and posttreatment etc.. The materials needed to provide the treating infrastructure were divided by the span of their life time in order to obtain the yearly amounts of cement, metals, asphalt etc. necessery to treat the 10'000 tons (assumptions: life span for mobile machines: 5a, stationary engines: 10a, Buildings: 25a). The ecological preinvestments to produce the building and the construction materials were included by taking the data from ECOINVENT, a data base tool developed by the Swiss Federal Institute of Technology, ETH (*Zimmermann, 1996*).

The ecological running costs of the plant included energetic and material parameters such as energy fluxes, parts replaced because of attrition, comodities etc. as well as the emissions into air and into water caused by the process.

Gas emissions

For the methane emissions of composting sites there exist only few data. In order to get appropriate values, the gaseous emissions were measured three times over the year by the closed chamber method (viz.fig.3). Because the amount of degraded organic matter (viz. fig. 1) and its carbon content is known, the moles of emitted carbon containing gas molecules can be calculated. Because CO_2 and CH_4 both contain just one carbon atom and have a similar volume requirement, it is possible to calculate their total emissions, as soon as their relative ratio is known.

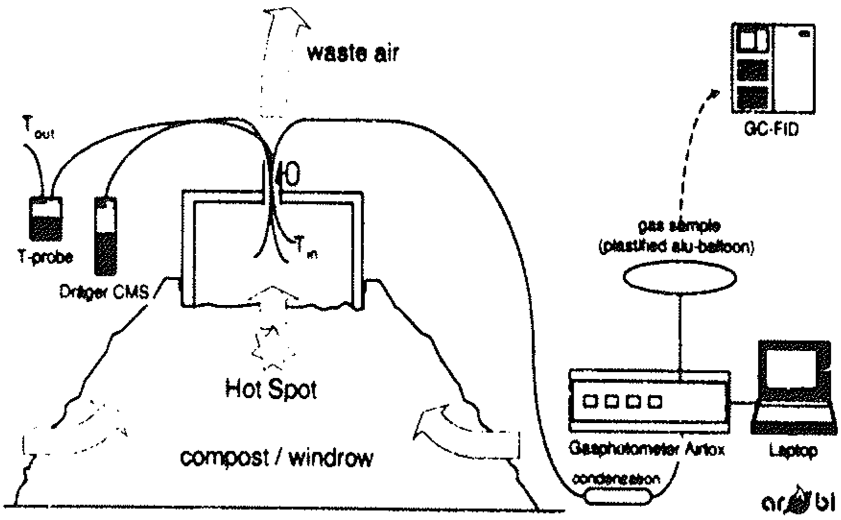


Figure 3:

The closed chamber method to measure the gaseous emissions of compost: A box is placed over the hot spot, where it will be filled by the (warm) ascending gases. The ratio of CO_2 to CH_4 to O_2 is monitored on line. For each process measurements of one half up to two hours each were made at different places on several composts of different ages or on the biofilters.

The box was insulated and with heating facilities in order to prevent condensation.

Ecobalances and sensitivities

After the determination of the mass fluxes, the emissions of these fluxes were determined and weighted. All raw material extraction, distribution and manufactoring processes were included up to the moment of building the plants. Two tools were used for the weighing of the impacts: An improved version of ECO-INDICATOR 95 (*Mark Goedkoop, 1995*) and UBP, a tool developed by BUWAL. The calculations as well as the evaluation of the data of waste incineration (*Hellweg, 1999*) were done by S.Hellweg at the Laboratorium für technische Chemie, ETH Zürich.

In ECOINDICATOR ten impact categories (such as geenhouse effect, ozone layer depletion, acidification etc.) have been defined. All the impacts caused by the different activities of a waste treating process are first sorted and attributed to the relevant categories. Afterwards they are brought to a comparable size by multiplying with a factor corresponding to their relative damage potential (eg. in the greenhouse effect methane is weighted - depending on the observation period - 21 times stronger than carbon dioxide). Then the effect scores can be normalized for each category. The damages are weighted for mortality, health and ecosystem impairment. For the damage weighting factors subjective weighing is possible. In this study, the default values of the software have been applied.

The method UBP of BUWAL was used to compare the results of ECOINDICATOR to a tool, where the target set value is the Swiss national policy objectives. In UBP normed Ecopoints are distributed not to the effects, but to individual emissions, energy consumption and environmental scarcity.

Because ECOINDICATOR only takes account of heavy metals leached from soil to water, sensitivities were calculated for different heavy metal washouts from grounds, where compost was applied. Additional sensitivities were established for emissions of NH_3, N_2O and H_2S (data from literature), optimization of reduction of methane emissions while digesting and for not giving benefits for the fertilizing properties while applying compost.

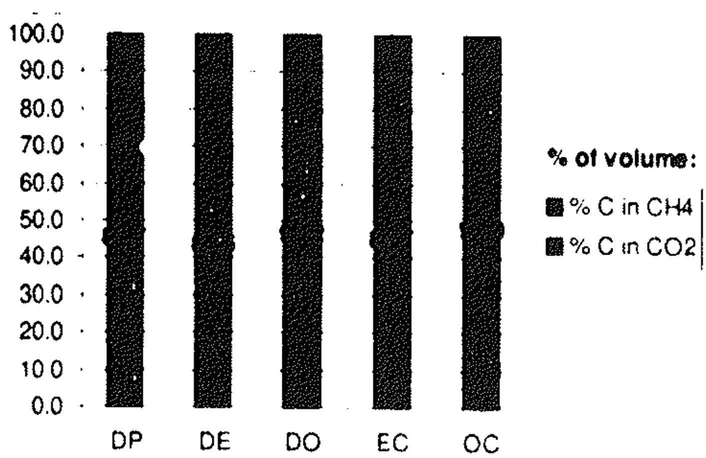
RESULTS

Gas emissions

Figure 4 shows that i.) even in composts, which are reversed very often (OC) there also exist significant methane emissions, and ii) in digestion plants there is a considerable potential of methane emission even if just a small part of the organic breakdown takes place outside the (enclosed) digester. The measurements were taken on existing plants. For reasons which cannot be discussed here it seems probable that - taking mass streams such as assumed - the emissions of DO will be rather higher and those of DP rather lower than shown in figure 4. For detailled gas analyses and discussion of the emissions see *Edelmann Schleiss, 1999.*

Figure 4:

Ratio of CO_2 to CH_4 of the different biotechnological processes (% of volume, mean values). The graph shows the ratio of the total of the emissions, i.e. the fact that different percentages of the substrate were composted depending on the technology applied was taken account of. The methane generated by anaerobic digestion is counted as CO_2 because it will be oxidized while being burnt in the engine/generator.



The gaseous emissions of NH_3, N_2O and H_2S were very low as compared to the emissions of CO_2 and CH_4 and difficult to measure accurately in the wet and warm gas emissions. Additional measurements have to be made to obtain data which are statistically significant. For this reason sensitivities were calculated with data taken from literature.

Ecobalances

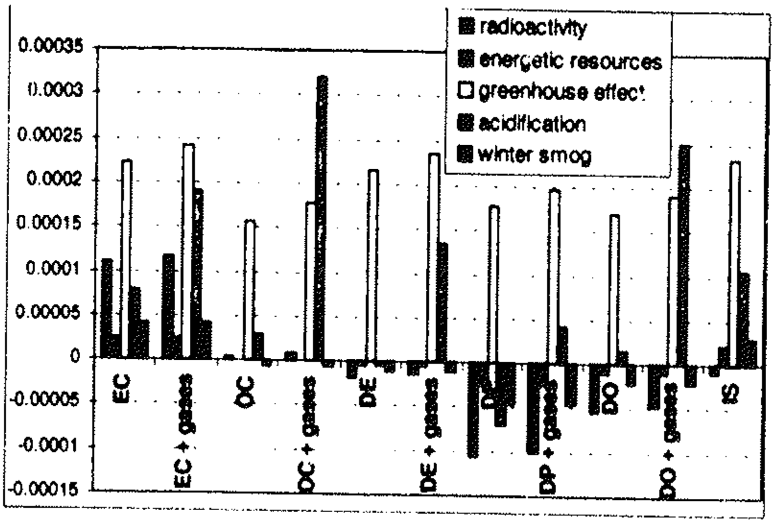


Figure 5:

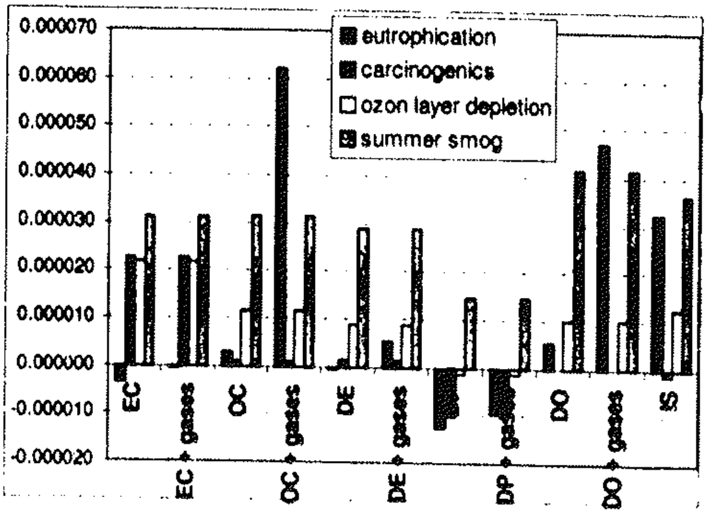
Ecoindicator 95+ -points for the impact categories radioactivity, energetic resources, greenhouse effect, acidification and winter smog. The data "+gases" of the biotechnological processes were calculated including emission data (taken from literature) for NH_3, N_2O and H_2S into the air. NH_3-emissions are reduced to a large extent by the biofilters of the fully enclosed plants (EC, DP and DE).

The radioactivity as well as much of the acidification is caused by the european electricty mixture (nuclear plants as well as thermic plants running on coal).

Figure 6:

Ecoindicator 95+ -points for the impact categories eutropnication, carcinogens, ozon layer depletion and summer smog. The data "+gases" of the biotechnological processes were calculated including emission data (taken from literature) for NH_3, N_2O and H_2S into the air.

The eutrophication becomes especially large in OC and DO for the sensitivity with gas emission, when ammonia is able to escape to the open air. Similar to figure 5, DP shows some negative values which are caused by the high net production of electricity that substitutes UCPTE-electricity.



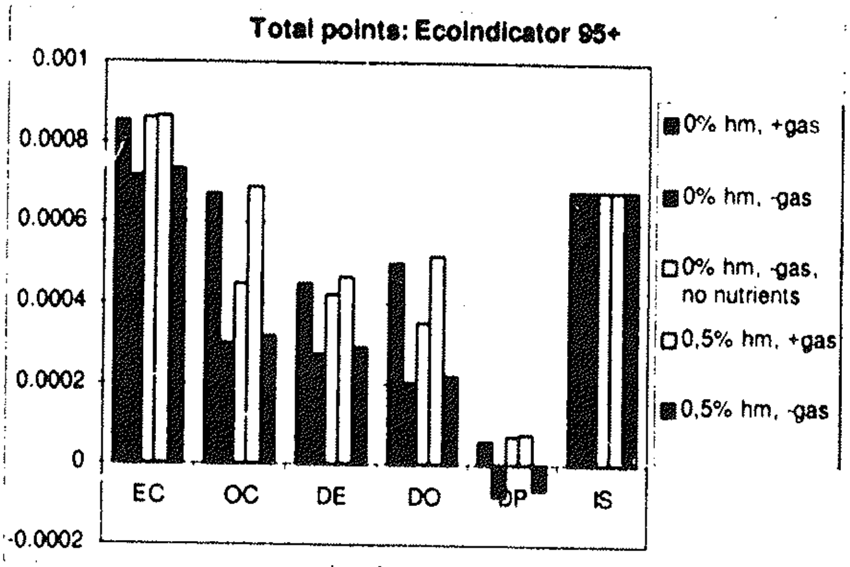


Figure 7:

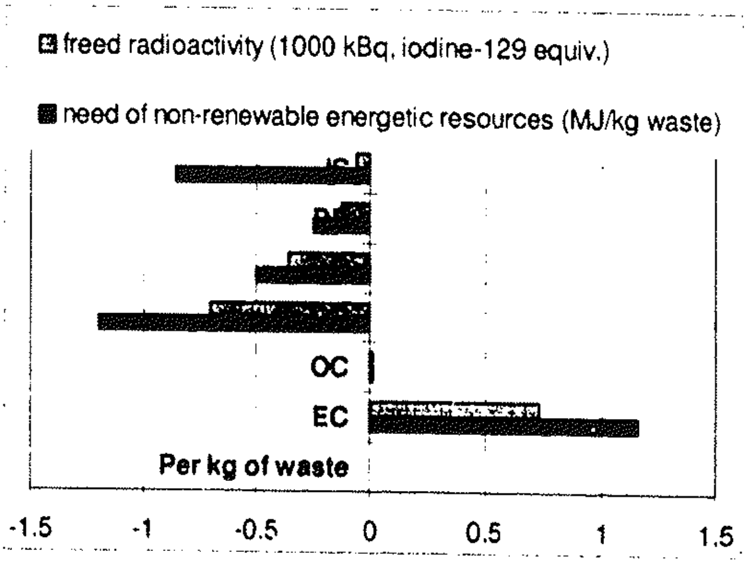
Total sums of ECOINDICATOR 95+ points for 4 sensitivities: hm: heavy metals leaching into the groundwater, +/- gas: with/without emission data for NH_3, N_2O and H_2S into the air. No nutrients: no benefit for fertilizer substituion.

For the incineration - evaluated by S.Hellweg, ETH-Z - no sensitivites were calculated, because not the same sensitivities are relevant for incineration as for biotechnolgical processes. Heavy metal leaching from ash dump was assumed to be 0,5%.

Figures 5 and 6 show the sums of the ECOINDICATOR 95+ points for 9 impact categories. For the nitrogen and phosphorus present in the compost, benefits corresponding to the savings of artifical fertilizer production were taken into account. In the incineration plant (IS) the nutrients are lost. In figure 7, which shows the total EI-points, a sensitivity is calculated without fertilizer benefit. The heavy metals are integrated in figure 7. ECOINDICATOR only takes heavy metals into account, if they are exported from the soil into the water. Different sensitivities were calculated for the heavy metal leaching. In figure 7 data are shown for no leaching and for 0,5% heavy metal export into water. With 5% export into water - which is a very high value - only DP has a slightly lower sum of EI total points than IS (not shown in fig.7). The comparison with the tool UBP showed the same ranking for the biotechnological treatments. However, because of the (very heavy) weighing of heavy metals remaining in the ground, only DP showed a better performance than IS for some sensitivities. For details see *Edelmann, Schleiss, 1999.*

Figure 8:

Freed radioactivity and need of non-renewable energetic resources while treating biogenic wastes with different methods. The very low energy need of OC is due to the benefit for fertilizer substitution.



Figures 7 and 8 show the overall performances and the energetical comparison of the processes. Energy plays a predominant role: EC shows energetical running costs of over 100 kWh per ton of waste which causes considerable negative impacts. In figure 8, IS shows large benefits mainly for selling waste heat, which was assumed not to be possible for digestion.

Economy

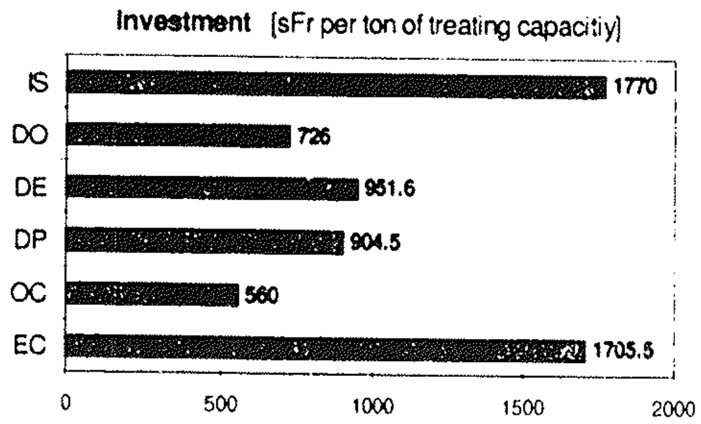


Figure 9:

Investment costs of the different processes: The investment costs for the incineration plant are derived from a project, which is under construction in Switzerland (incineration plant with advanced gas scrubbing and selective catalytic reduction of NOx)

The investment costs of the fully automated EC is very high; it may be suggested however, that it could be possible to construct a new plant of similar design with some financial savings.

The costs of the different processes were inquired at existing plants (*Schleiss et al., 1998*) and afterwards corrected for plant sizes with treating capacities of 10'000 tons/year. The data of IS refer to a plant with a capacity of 100'000 t/year including the organic fraction into the "grey" bag. Detailed information is given in *Edelmann, Schleiss, 1999.* The costs for waste collection are not included in fig.10. For biotechnological treatment they can be assumed to be identical. With incineration it is not necessary to collect twice ("grey" and "green"), but the transporting distances are longer due to the larger radius of the collection area caused by the higher treating capacity.

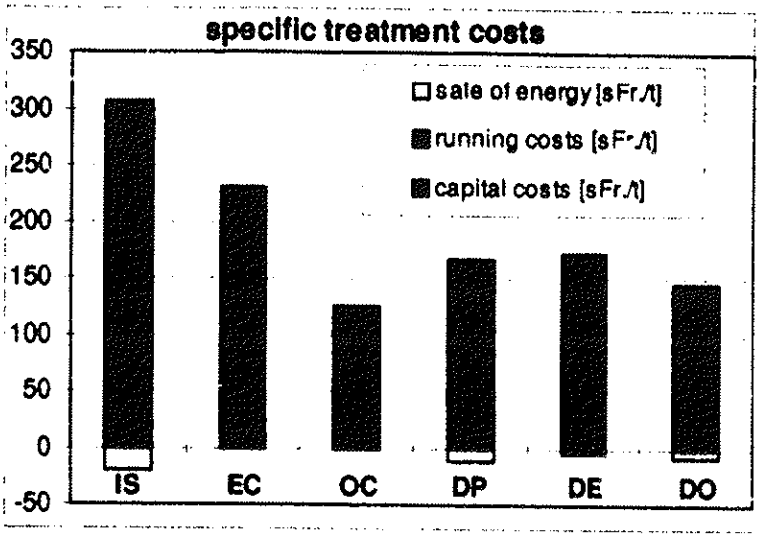


Figure 10:

Specific treatment costs of the different processes: OC shows the lowest treatment costs due to the relatively low investment. (The running costs of OC are higher than those of the other biotechnological treatments because of lower automatization).

DO is slightly cheaper than the other digestion technologies because of lower investment (open composting without biofilter etc.), but it is not suited for all applications (high content of kitchen wastes etc.). EC shows the lowest running costs, but very high investment costs which cause high capital costs.

DISCUSSION OF THE RESULTS

The ecological and the economic comparisons (figures 7 and 10) show that the biotechnological treatments for biogenic waste treatment are generally favorable to incineration. The pure composting technologies (EC and OC) appear to be less ecological than digestion.

The three catégories greenhouse effect, acidification and heavy metals play an important role in the ecobalance.The greenhouse effect is caused mainly by CO_2 and CH_4. CO_2 emission cannot be prevented if biogenic matter is degraded.The CH_4 emissions count 21 times more than CO_2. It is not surprising that a considerable amount of methane is emitted while composting (*Edelmann, 1995*). A large improvement potential exists especially for the composting part in digestion plants i.) by obtaining after digestion aerobic conditions as quickly as possible and ii.) by eventually improving the biofilter performance.

Heavy metals have a very strong effect in UBP and also in ECOINDICATOR 95, provided that there exists an export into the water. Heavy metals are deposited by rain and air on the biomass which afterwards is treated in a processing plant. The treatment itself does not attribute significantly to the heavy metal load of the biomass (metal deriving from chopping and from transporting engines etc.). Because the heavy metals are supposed to be in a more or less inert form bound in the ashes of the dump, IS shows an advantage: in this case the heavy metals are withdrawn from ecological cycles. Considering the fact that the heavy metal load of the compost usually is far below the legal limits, it does not seem logical yet to burn the (precious) organic substance in order to reduce heavy metals present in air and rain.

When comparing the different technologies, energy plays a predominant role. Digestion plants are better from an ecological point of view, because they don't need external fossil and electrical energy. If only one quarter of the biogenic waste is digested, a plant can be self sufficient in energy (*Edelmann, Brotschi, Joss,1998*). The production of renewable energy has positive consequences on nearly all impact categories, because of saving of or compensation for nuclear and fossil energy. This reduces the impacts of parameters such as radioactivity, dust, SO_2, CO, NOx, greenhouse gases, ozon depletion, acidification or carcinogenic substances. Digestion plants could show an even better ecobalance, if they were constructed near an industry which can use the waste heat of electricity production all year round.

It is nearly impossible to take advantage of waste heat while composting (*Edelmann et al.,1993*). Looking at the results of the ecobalance and the economic situation, it is difficult to understand that today composting plants are constructed, where high value fossil and nuclear energy is invested to *destroy* the renewable solar energy, which is fixed in the chemical compounds of biomass and thus in the biogenic waste.

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