Title	**A technical theoretical framework for ECOSAN applied to the medium sized Danish town Hillerød**
Keywords	ecological sanitation, recirculation, organic waste, human urine, urban waste management, urban fertilizers
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Short CV for introduction purposes	Associate Professor in Soil Fertility and Plant Nutrition. In recent years his work has been part time as managing director of a university consortium building educations on the topic of 'Sustainable Land Use and Natural Resource Management'. In the remaining time he has dealt with nutrient and waste management in land based production systems. He is responsible for developing integrated research on 'Recirculation of nutrients from urban to rural areas' spanning components from agricultural, technical, public health and social sciences.
Photograph attached	

Introduction

Previously, in large parts of Europe and many other parts of the world, peri-urban farmers were dependent on deliveries of 'night soil' from urban areas in order to replenish the fertility of the land. In Japan the recycling of urine and faeces was introduced in the 12th Century and in China human and animal excreta have been composted for thousands of years. Such recirculation systems can still be found in parts of Asia, but are deteriorating in the face of the rapid development process, not least in the mega-cities that draw heavily upon the natural resources in their hinterlands. Thus Færge et al. (2001) assessed that for Bangkok only 7 and 10% of the N and P in the total food supply was recovered for agricultural use, the main part of the N being transported into the surrounding sea but with a large part of the P accumulating in the metropolitan area. In an ecological analysis this cannot be sustainable, since in many cases farmers in the hinterland cannot replace the nutrients they export to the urban areas with their products by mineral fertilizer, and the surrounding sea is becoming increasingly polluted.

In Northern Europe today, waste water management systems have developed to maturity without primary concern for recycling (Magid et al., 2001). These systems were originally designed to get rid of waste in order to better the local hygienic standard using water as a transport media. More recently environmental concerns have been the driving force behind a technological development of sewage treatment with biological removal of N, P and organic matter, thus increasing the costs for waste water treatment. This technology addresses some immediate problems in the aquatic environment, but the sewage sludge from the treatment plants contain considerable quantities of xenobiotic compounds and heavy metals, and only a small fraction of the nutrients that entered the urban areas, thus making the sludge a non-attractive fertilizer source. In recent years there has been concern about the sustainability of this state of affairs as regard to wastewater handling, as well as concern about the fate of the final waste deposits in the environment. An integrated study commissioned by the Danish EPA was undertaken to develop and evaluate technical solutions for increasing recirculation. It included assessment of technical solutions feasibility in a specific medium modern town setting – the municipality of Hillerød, and tentatively scaling up the implementation of such solutions to a national level. The results of this work is reported in the following.

Methods

In order to assess the recirculation potential from Danish households a resource production model was set up **(Table 1)**.

Table 1. Overview of the production of household wastes based on physiological excretion of nutrients and water. (liter/person/year and kg/person/yr).

			Physiological		Kitchen		
Substance	Unit	Total	Feces	Urine	Water	Solid	Bathing & washing
Volume of resource excl. water usage	liter/(p*year)	793	75	430	150	130	7,5
Water usage	liter/(p*year)	54750	7300	10950	18250	0	18250
Total volume	liter/(p*year)	55543	7375	11380	18400	130	18258
Total dry weight	kg/(p*year)	86	13	22	15	29	7,3
Total wet weight	kg/(p*year)	725	75	440	115	87	7,5
COD	kg/(p*year)	80	22	5,5	16	33	3,7
BOD	kg/(p*year)	33	7,3	1,8	11	11	1,8
Nitrogen	kg/(p*year)	6	0,37	4	0,37	0,62	0,37
Phosphorus	kg/(p*year)	1	0,18	0,55	0,07	0,11	0,11
Potassium	kg/(p*year)	2	0,37	0,91	0,15	0,15	0,15

Based on data from : Dahi (1990); Henze (1997); Danish EPA (1993b); Danish EPA (1994); Danish EPA (1997); Swedish EPA (1995))

Since persons only spend part of their time in the household premises, it will be possible to recover only a fraction of the different wastes directly from the households. The recoverable fraction is assumed to be:

50 % of urine, 75 % of faeces, 90 % of the solid organic waste, and
90 % of the grey water (water used for washing, bathing and kitchen purposes).

On this basis it was delineated which types of wastes should be handled with the view to enhance recirculation, and a number of handling systems were designed based on known technologies (Wrisberg et al., 2001). The handling systems were assessed for their usability in various built environments:

- Dense urban centre (building blocks in dense formation)
- Open urban centre (older houses 1-2 storey in dense formation)
- Flats with surrounding open spaces
- Chain houses (1-2 storey, dense low)
- Villa's (single houses with surrounding open space)
- Allotments (small plots with shacks used in spare time for leisure and food production)

Design of alternative waste management systems
Alternative waste management systems were designed based on known components, that were assumed to be able to meet minimum standards in relation to public health, comfort, costs, durability and user friendliness. They were selected on the assumption that they could be acceptable in society today, and both local and central handling of waste was included.

Integration of systems into an existing medium sized town
An integrated sewage and organic waste management system for an established medium sized town, Hillerød (app. 27.000 inhabitants), was developed in collaboration with the technical advisors for the municipality. This was based on the aforementioned alternative waste management systems and a detailed analysis of the local conditions and most feasible redevelopment schemes.

Assessment of the potential for recirculation on a regional and national scale
Based on production and delivery potentials at regional level, and the distribution of stockless agricultural production systems, it was calculated to which extent recirculation could substitute current agricultural use of mineral fertilizer (N, P and K)

Results
The resource production overview demonstrates that the primary volume of waste is limited to approximately 800 L per person per year, including physiological excreta, kitchen waste and bathing and washing resources (mainly soap and detergents), see table 1. However when the water usage is included the total volume is increased by a factor 70 to approximately 56 m^3 per person per year. The basic assumption in the design of alternative waste handling systems has been that it is possible to design handling and storage systems that will allow a collection of the waste resources to be contained within 2-3 m^3 per person per year for transport by road, and that the remaining water (53 m^3) may be handled in more or less local systems, depending on existing or future infrastructure.

It is notable that the urine fraction contains 50-67% of the total macronutrient resource and thus exceeding the solid fractions (feces and solid kitchen waste) by far, see table 1. These solid fractions contain the major part of COD and BOD, which has led to an interest in systems that can divert urine from toilets as a separate resource.

Integration of systems into an existing medium sized town

Selected systems for Hillerød

When choosing a system for a city there is a necessity to consider the local conditions. Before choosing the systems the housing types must be characterised, the amount of waste estimated and the housing type situation must be mapped. The evaluation of the systems and the housing types defined the chosen systems. In Hillerød City the number of inhabitants was 26.818 persons. As a baseline the technical staff of the municipality decided that biogas production from waste should be given priority. Hillerød was divided in to nine housing areas, with different kind of housing. For each area a handling system was chosen, which was considered the best regarding the housing type. In total four handling systems were chosen for the nine areas (see figures 1-4). System 1 (see figure 1) was chosen for housing in the centre of the town, because there was not enough space for implementing systems with separate urine or faeces collection. It would also be difficult to collect urine with a truck in the narrow streets. System 2 with separate urine collection was chosen for housing areas with self-contained houses, row houses, apartments, and for houses in the rim of the centre. In these areas there would be enough space for collecting tanks and for local use of organic kitchen waste. However, everywhere the kitchen waste was used for biogas production because of the energy potential in the waste. It was decided not to collect faeces because of the many apartment houses in the area. In our scenarios collection of faeces implies use of vacuum toilets, and the noise from these toilets was assumed perhaps erroneously to be an unacceptable nuisance in apartment houses. System 3 was chosen for housing areas with row houses and self-contained houses. Collection of faeces is possible here because it is houses with only one family. System 4 was chosen for allotments, because they are not provided with sewers. The allotments are the only kind of housing where the land area is large enough to permit reuse of all the waste products locally. A general conclusion is that the closer to the town centre the fewer systems can be used because of limited space for the collecting technologies.

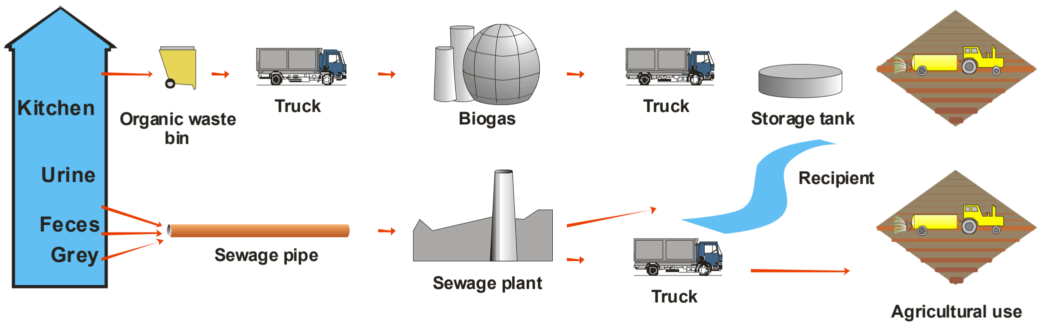

Figure 1. Kitchen waste is treated in a biogas plant. Urine feces and grey water are treated in a wastewater plant.

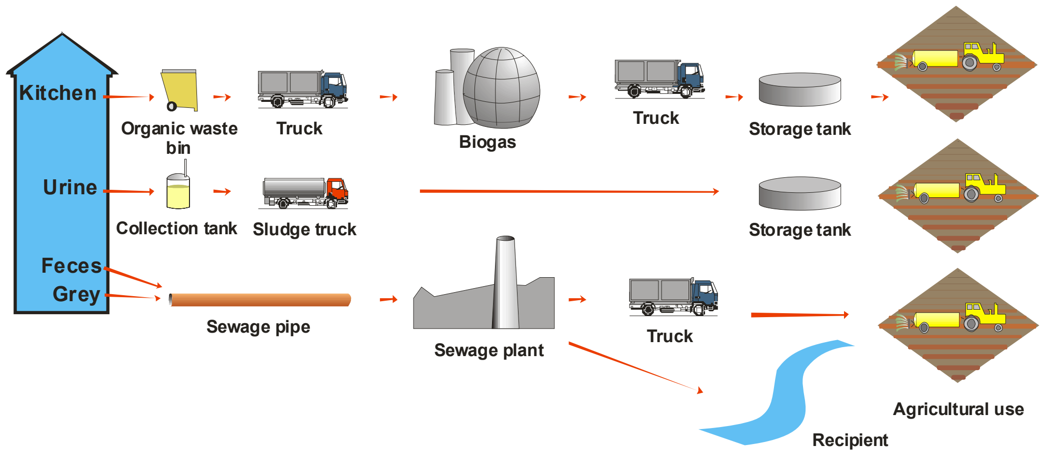

Figure 2. Kitchen waste is treated in a biogas plant. Urine is collected separately, feces and grey water are treated on a wastewater plant.

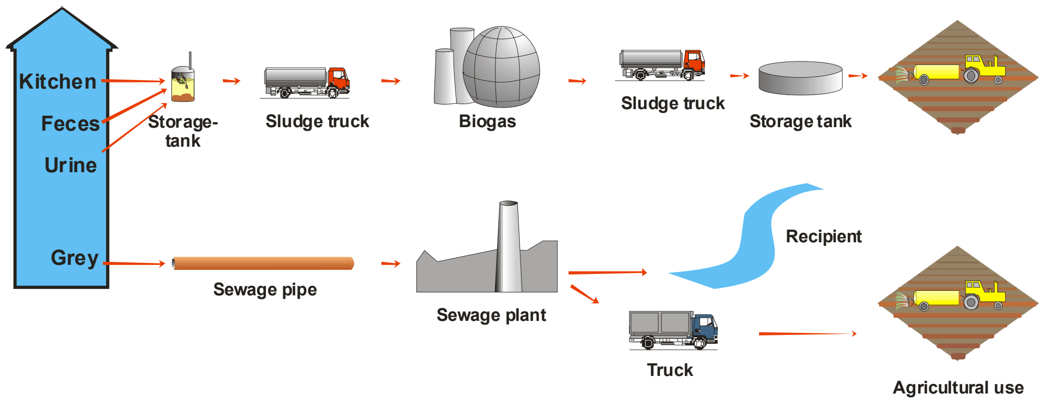

Figure 3. Kitchen, feces and urine are treated in a biogas plant, grey water is treated on a wastewater plant.

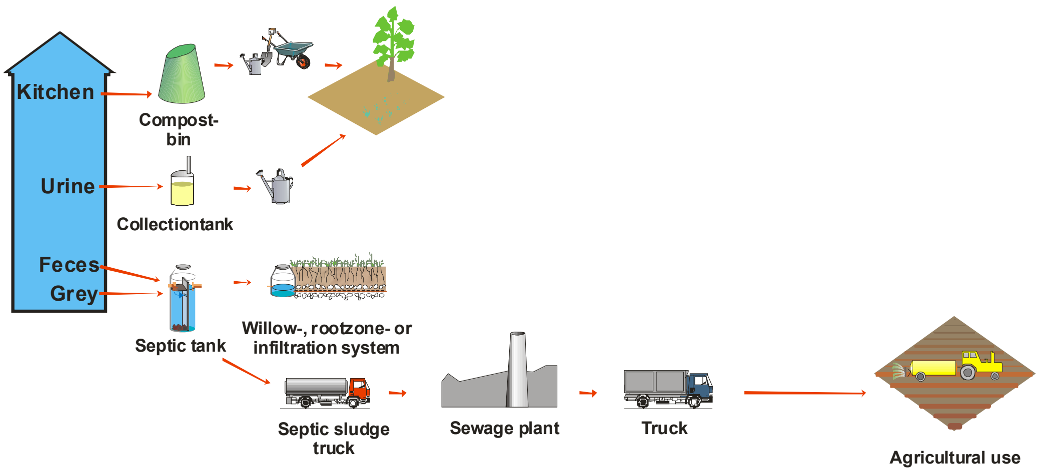

Figure 4. For community garden projects. Kitchen waste and feces are composted. Urine is collected while grey water is infiltrated into soil.

Consequence of the system change

The 4 chosen systems for Hillerød were compared with a reference system (table 2).

Table 2. Comparison of energy consumption, economy and recycling potential per cap/year, for four chosen systems and a reference system. (Negative energy consumption indicates an energy surplus)

	Unit	System 1	System 2	System 3	System 4	Reference-system
Energy consumption	KWh	-103	-129	-118	-28	7,27
Economy:						
Running cost /year	€	292	373	379	284	302
Capital cost	€	3892	4714	4728	3376	4000
Recycling potentials:	kg N kg P kg K	1,14 0,58 0,19	2,53 0,57 0,66	3,21 0,53 0,84	2,19 0,54 0,81	0,85 0,57 0,20

A system where the organic kitchen waste would be composted in a central place, while wastewater was treated in a conventional waste water treatment plant was chosen as reference system. This reference system is in use in many cities today. The chosen systems were compared with the reference system according to economy, energy consumption and the amount of nutrients collected. A comparison of the energy consumption (table 4) shows that there is an energy gain by choosing the four systems and energy consumption by choosing the reference system. System number 4, chosen for allotments and system number 1 chosen for the town centre are slightly less expensive to construct and run than the reference system, while system 2 and 3 are a little more expensive. All the chosen systems are more effective regarding recycling of nitrogen and potassium, than the reference system. In recycling phosphorus there is no substantial difference.

The reference system is compared with the integrated alternative four housing systems for Hillerød in table 3. The energy consumption for the reference system corresponded to the electricity consumption in 53 Danish households per year. For the chosen system the energy surplus is corresponding to the yearly electricity consumption in 896 Danish households. The annual cost for the 4 chosen systems is 17 % higher than for the reference system including the net energy savings. The accumulated nutrient in the reference system would be sufficient for fertilising 152 hectare of agricultural field, provided that the sludge complies with the standards for agricultural usage. In the 4 alternative systems the nutrients are collected as sludge from biogasdigestor, human urine and sludge from the wastewater treatment plant. The nutrients collected are enough for fertilising 451 hectare of agricultural field, corresponding to 12 % of Hillerød municipality's area.

Table 3 Comparison of four chosen systems and a reference system for 26.818 persons in Hillerød city

	Unit	The four chosen system	Reference system
Energy consumption	kWh	- 3.269.601	194.966
Economy:			
Running costs/year	mio. €	9.7	8.1
Capital costs	mio. €	119	107
Recycling potentials:	Kg N kg P kg K	67.702 15.065 17.526	22.795 15.286 5.363

Recirculation on a regional and national scale

From figure 6 it may be seen that nitrogen recovered from urban sources could potentially cover the need for 80% of current mineral fertilizer N used in the Copenhagen metropolitan area, which is the most densely populated human settlement in Denmark. In other regions the coverage is substantially less, so in the current agricultural systems there is sufficient scope to absorb the potential urban fertiliser on a national scale. This also turned out to be the case for potassium and phosphorus, albeit a moderate excess of P was identified in the Copenhagen metropolitan area.

Conclusion

It is technically possible to design integrated ecological waste management systems, based on known components that may be operated at or close to the cost level of the current conventional sanitation systems. A number of possibilities exist for increasing recirculation of nutrients and organic matter from urban areas and reducing the energy consumption related to waste management. Such integrated systems need to be technologically developed and tested on a scale that will allow an interaction with farmers and their organizations, in order to evaluate their wider environmental consequences. Furthermore, there is a need to integrate health and socio-cultural aspects in a learning process. The main drivers for change in the parts of the world where centralized sewage systems are fully installed would seem to be either government policy motivated (sustainability drive) or motivated by grass root movements, since the economic incentives for technology change are currently uncertain and probably small. However in the worlds middle income countries there is a considerable need for development of waste and sanitation infrastructure, which would give ecological sanitation some scope for further development.

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