Possibilities and barriers for recirculation of nutrients and organic matter from urban to rural areas: A technical theoretical framework applied to the medium-sized town Hillerød, Denmark

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\textbf{ABSTRACT}

We aimed to develop and evaluate technical solutions for increasing recirculation of nutrients and organic matter from urban areas. Furthermore, we assessed the feasibility of the solutions in a specific medium-size modern town setting – the municipality of Hillerød (approx. 27,000 inhabitants), Denmark. Fourteen integrated systems were described based on well-known technology and assessed on the basis of their ability to meet requirements in relation to public health, comfort, costs, durability, user friendliness, energy use, and recirculation potential. Of these 14, four were used to ‘retrofit’ into the existing town in an integrated municipal sewage and organic waste management system and the resulting change in terms of energy balances, recycling, and economic costs were modeled against a conventional ‘reference’ waste management system. For the chosen systems the energy saving corresponded to the yearly electricity consumption in 896 Danish households. It was estimated that capital and running costs were approximately 10% and 17% higher than for the reference system, including the net energy savings. The reference system produced sufficient nutrients for fertilising 152 ha of agricultural field, whereas the alternative system in which nutrients were collected as sludge from biogas digester, human urine, and sludge from the wastewater treatment plant were enough for fertilising 451 ha of agricultural land.

On the basis of this work it can be concluded that it is technically possible to design integrated ecological waste management systems, based on known technical components that may be operated at or close to the cost level of the current conventional sanitation systems. Such integrated systems need to be further developed and tested on a scale that will allow an interaction with farmers and their organizations, in order to evaluate their wider environmental consequences and to further integrate health and socio-cultural aspects. The main drivers for change in countries with a fully developed centralized sewage and waste infrastructure would seem to be either government policy-motivated (sustainability...
1. 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 feces was introduced in the 12th century and in China, human and animal excreta have been composted for thousands of years. Such recirculating 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 and Magid (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 apart from the energy costs 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, wastewater 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 wastewater 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.

This concern was compounded during a period where farmers organizations advised their members to refuse receiving sludge before a guarantee was given by the Danish EPA that their food would not be considered unsafe. While such a guarantee was never given farmers actually refused to receive sludge for a prolonged period, leaving local municipalities with heaps of sludge, and stimulating a costly incineration of sludge. Organic farmers felt particularly strongly that something should be done about the state of affairs, and requested that some research into alternative waste management systems was carried out. Furthermore, since maintenance of the established systems will necessitate considerable investments in the future, there has been an interest in alternative systems for wastewater management.

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. This work was based on selecting appropriate technologies for lessening some adverse ecological impacts of existing built environments as well as new urban structures to be built from the ground. Thus, in one sense it is on the edge of ecological engineering (Bergen et al., 2001), since it is partially limited by retrofitting into existing structures. The main thrust of this assessment is the increasing use and recycling of food and energy resources, and thus a partial recovery of the ecosystems affected (back to food).

2. Methods

2.1. The resource production model

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

Since persons spend only a 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:

1. 50% of urine,
2. 75% of feces,
3. 90% of the solid organic waste,
4. 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 enhanced 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:

1. Dense urban centre (building blocks in dense formation).
2. Open urban centre (older houses 1–2 storey in dense formation).
3. Flats with surrounding open spaces.
5. Villa’s (single houses with surrounding open space).
6. Allotments (small plots with shacks used in spare time for leisure and food production).
2.2. Public health issues in connection with ecological sanitation systems

Analysis of public health issues has been central in the development of the systems, since the attainment of sufficient public health safety is a killer assumption that must be satisfied in Danish society regardless of other technical and economic and socio-cultural problems.

2.3. Source separated urine

Human urine does not generally contain pathogens that can be transmitted through the environment (Höglund, 2001; Dalsgaard and Tarnow, 2001). However, one inevitable source of pathogens in urine collected from the urine-diverting toilets is cross-contamination from feces. In Sweden, guidelines have been developed (Schönning and Steenström, 2004) on how to use source separated urine in agriculture in order to control the risks of transmission of infectious diseases as a part of risk management. Regulatory standards or guidelines have yet to be determined by the agency responsible for Sweden. In practice, Danish regulatory standards require that urine is stored 6 months in a sealed container before use, and the usage conforms to the standards of sewage sludge use.

2.4. Other waste products

Feces, organic household waste, and mixtures of feces, urine, and household waste must undergo a hygienization treatment before being reused in agriculture, in order to be acceptable (Blumenthal et al., 2000). Treatment in biogas plants, centralized composting facilities, and wet composting plants will be appropriate for a controlled hygienization, but recent research has questioned if local composting of fecal material in composting toilets is sufficient, due to possibly incomplete thermal hygienization during the composting in relatively small containers. However, the practice of dry composting is commonly used in Scandinavia today in connection with sanitation in second homes in rural settings, and in certain allotment garden systems as well.

2.5. Design of alternative waste management systems

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 black water waste resources (urine, feces, and organic household waste) to be contained within 2–3 m³/person/yr for transport by road, and that the remaining water (53 m³) may be handled in more or less local systems, depending on existing or future infrastructure. Such technological approaches have been described previously, with a main emphasis on local grey water treatment (Dallas et al., 2004; Günther, 2000), or human urine (Adamson, 2000; Lind et al., 2001).

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. In some Scandinavian locations, the treatment of organic waste is based on wet composting with forced aeration. Such solutions were included in the initial screening of possible systems, but later on rejected on the basis that the energy balance was too much in their disfavor.

2.6. Calculation of energy consumption, cost and recirculation potential

The method of calculation of energy consumption, cost, and recirculation potential is described in Eilersen (2001). In brief, the energy budget includes production from incineration or biogas, consumption related to transportation plus energy savings related to substitution of chemical fertilizer and reduced water consumption due to water savings. Costing includes capital and running costs of the housing system and transport infrastructure, discounted at the annual rate (6%) recommended by the Danish ministry of finance. The calculations are based on differentiated life spans for the various components.

2.7. The reference system

A system where the organic kitchen waste would be composted in a central place while wastewater was treated in a conventional wastewater treatment plant was chosen as reference system. This reference system is in use in many cities today.

2.8. Integration of systems into an existing medium-sized town and assessment of the potential for recirculation at county level and national scale

When choosing a system for a city there is a necessity to consider the local conditions (Bergen et al., 2001). 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.

An integrated sewage and organic waste management system for an established medium-sized town, Hillerød, Denmark (approx. 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.

The production and delivery potentials in each of Denmark’s 12 counties was based on the number of inhabitants. The extent to which recirculation could substitute current agricultural use of mineral fertilizer (N, P and K) was based on the distribution of stockless agricultural production systems (Wrisberg et al., 2001), in which it was assumed that nutrients collected from the Ecological Sanitation systems could replace compound fertilizers currently used.

3. Results

The resource production overview demonstrates that the primary volume of waste is limited to approximately
Table 1 – Overview of the production of household wastes based on physiological excretion of nutrients and water (L/person/yr and kg/person/yr)

<table>
<thead>
<tr>
<th>Substance</th>
<th>Total</th>
<th>Physiological</th>
<th>Kitchen</th>
<th>Bathing and washing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Feces</td>
<td>Urine</td>
<td>Water</td>
</tr>
<tr>
<td>Volume of resource excl. water usage (L/(p yr))</td>
<td>793</td>
<td>75</td>
<td>430</td>
<td>150</td>
</tr>
<tr>
<td>Water usage (L/(p yr))</td>
<td>54750</td>
<td>7300</td>
<td>10950</td>
<td>18250</td>
</tr>
<tr>
<td>Total volume (L/(p yr))</td>
<td>55543</td>
<td>7375</td>
<td>11380</td>
<td>18400</td>
</tr>
<tr>
<td>Total dry weight (kg/(p yr))</td>
<td>86</td>
<td>13</td>
<td>22</td>
<td>15</td>
</tr>
<tr>
<td>Total wet weight (kg/(p yr))</td>
<td>725</td>
<td>75</td>
<td>440</td>
<td>115</td>
</tr>
<tr>
<td>COD (kg/(p yr))</td>
<td>80</td>
<td>22</td>
<td>5.5</td>
<td>16</td>
</tr>
<tr>
<td>BOD (kg/(p yr))</td>
<td>33</td>
<td>7.3</td>
<td>1.8</td>
<td>11</td>
</tr>
<tr>
<td>Nitrogen (kg/(p yr))</td>
<td>6</td>
<td>0.37</td>
<td>4.5</td>
<td>0.37</td>
</tr>
<tr>
<td>Phosphorus (kg/(p yr))</td>
<td>1</td>
<td>0.18</td>
<td>0.55</td>
<td>0.07</td>
</tr>
<tr>
<td>Potassium</td>
<td>2</td>
<td>0.37</td>
<td>0.91</td>
<td>0.15</td>
</tr>
</tbody>
</table>


800 L/person/yr, 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 m³/person/yr.

It is notable that the urine fraction contains 50–67% of the total macronutrient resource 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.

Thus, initially 14 systems were designed that were considered to be feasible solutions for established and newly developed housing areas; however, based on a later assessment of performance indicators, such as local hygiene, durability and maintenance, technological level, use and cleaning, local participation, and flexibility, it was decided to exclude two of the fourteen systems. The remaining 12 systems are roughly described in Tables 2 and 3, using the original name code from Wrisberg et al., 2001, for ease of reference.

As can be seen from Table 3, there is a large difference in energy use of the selected systems. In most of the systems the main energy savings arise from decreased use of mineral fertilizer for agricultural land (Wrisberg et al., 2001); however, in systems with biogas treatments of feces and solid organic waste, approximately 100 kW/person/yr may be recovered additionally in energy that can be directly converted to electricity or biofuel. The estimates of annual costs per person are necessarily of uncertain nature, since systems like these in most cases have to be tried out in practice. The cost assessment for the existing and new housing reference is based on conservative estimates, whereas the cost assessments for alternative systems may prove in practice to be overestimated, since there is a considerable scope for the improvement of system efficiencies.

### 3.1. Integration of systems into an existing medium-sized town

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 into nine housing areas, with different kinds 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 Figs. 1–4). System 1 (see Fig. 1) was chosen for housing in the centre of the town, because there was not enough space...
### Table 3 – Key figures for energy use, cost and recirculation potential per capita/year for the 12 selected systems (negative energy use implies net energy saving or production)

<table>
<thead>
<tr>
<th>Per Capita</th>
<th>Energy consumption (kWh/yr)</th>
<th>Annual cost (€/yr)</th>
<th>Recirculation potential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kg N/yr</td>
</tr>
<tr>
<td>E1 (N8), Existing housing reference</td>
<td>7.3</td>
<td>302</td>
<td>0.85</td>
</tr>
<tr>
<td>E2 Urine collection</td>
<td>−27.9</td>
<td>358</td>
<td>2.53</td>
</tr>
<tr>
<td>E3 (N9) Urine collection</td>
<td>−19.2</td>
<td>382</td>
<td>2.58</td>
</tr>
<tr>
<td>E6 Biogas treatment</td>
<td>−118</td>
<td>382</td>
<td>3.21</td>
</tr>
<tr>
<td>E8 (N3) Urine collection</td>
<td>−28</td>
<td>284</td>
<td>2.19</td>
</tr>
<tr>
<td>N1 New housing reference</td>
<td>−1.4</td>
<td>278</td>
<td>0.8</td>
</tr>
<tr>
<td>N2 Urine collection</td>
<td>−24.9</td>
<td>296</td>
<td>2.11</td>
</tr>
<tr>
<td>N3 (E8) Urine collection</td>
<td>−28</td>
<td>284</td>
<td>2.19</td>
</tr>
<tr>
<td>N4 Wet composting</td>
<td>14.6</td>
<td>296</td>
<td>2.9</td>
</tr>
<tr>
<td>N6 Biogas treatment</td>
<td>−116</td>
<td>308</td>
<td>2.9</td>
</tr>
<tr>
<td>N8 (E1) New housing reference</td>
<td>7.3</td>
<td>302</td>
<td>0.85</td>
</tr>
<tr>
<td>N9 Urine collection</td>
<td>−19.2</td>
<td>382</td>
<td>2.58</td>
</tr>
</tbody>
</table>

**Fig. 1** – Kitchen waste is treated in a biogas plant. Urine feces and grey water are treated in a wastewater plant. Equivalent to E1 (Table 2), but with biogas treatment of organic waste.

For implementing systems with separate urine or feces 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, flats, 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 feces because of the many apartment houses in the area. In our scenarios, collection of feces 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

**Fig. 2** – Kitchen waste is treated in a biogas plant. Urine is collected separately, feces and grey water are treated on a wastewater plant. Equivalent to E3 (Table 2), but with biogas treatment of organic waste.
row houses and self-contained houses. Collection of feces is possible here because there are 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.

3.2. **Consequence of the system change**

The four chosen systems for Hillerød were compared with a reference system (Table 4) with regard to economy, energy consumption, and the amount of nutrients collected (Fig. 5). 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 5. 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 four 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 ha of agricultural field, provided that the sludge complies with the standards for agricultural usage (Danish EPA, 2000 ref). In the four alternative systems, the
Table 4 – Comparison of energy consumption, economy and recycling potential per capita/year, for four chosen systems and a reference system. (Negative energy consumption indicates an energy surplus)

<table>
<thead>
<tr>
<th></th>
<th>System 1</th>
<th>System 2</th>
<th>System 3</th>
<th>System 4</th>
<th>Reference-system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption (kWh)</td>
<td>−103</td>
<td>−129</td>
<td>−118</td>
<td>−28</td>
<td>7.27</td>
</tr>
<tr>
<td>Economy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running cost/year (€)</td>
<td>292</td>
<td>373</td>
<td>379</td>
<td>284</td>
<td>302</td>
</tr>
<tr>
<td>Capital cost(€)</td>
<td>3892</td>
<td>4714</td>
<td>4728</td>
<td>3376</td>
<td>4000</td>
</tr>
<tr>
<td>Recycling potentials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg N</td>
<td>1.14</td>
<td>2.53</td>
<td>3.21</td>
<td>2.19</td>
<td>0.85</td>
</tr>
<tr>
<td>kg P</td>
<td>0.58</td>
<td>0.57</td>
<td>0.53</td>
<td>0.54</td>
<td>0.57</td>
</tr>
<tr>
<td>kg K</td>
<td>0.19</td>
<td>0.66</td>
<td>0.84</td>
<td>0.81</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Fig. 5 – The layout of the chosen systems in Hillerød.

Table 5 – Comparison of four chosen systems and a reference system for 26,818 persons in Hillerød city

<table>
<thead>
<tr>
<th></th>
<th>The four chosen systems</th>
<th>Reference system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy consumption (kWh)</td>
<td>−3,269.601</td>
<td>194.966</td>
</tr>
<tr>
<td>Economy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Running costs/yr (mio. €)</td>
<td>9.7</td>
<td>8.1</td>
</tr>
<tr>
<td>Capital costs (mio. €)</td>
<td>119</td>
<td>107</td>
</tr>
<tr>
<td>Recycling potentials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kg N</td>
<td>67.702</td>
<td>22.795</td>
</tr>
<tr>
<td>kg P</td>
<td>15.065</td>
<td>15.286</td>
</tr>
<tr>
<td>kg K</td>
<td>17.526</td>
<td>5.363</td>
</tr>
</tbody>
</table>

nutrients are collected as sludge from biogas digestor, 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.

3.3. Recirculation on a regional and national scale

From Fig. 6 it may be seen that the 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 the 11 other counties, the substitution of mineral fertilizer N would require substantially less area, so in
4. Discussion

In the formulation of the project it was implicitly assumed that a recovery of nutrients and organic matter from the urban areas should be returned to the local food system. This assumption seemed obvious in the local Danish context but is in itself a value statement (sensu Bergen et al., 2001) that occurs naturally from the local context: Denmark is a small country that is strongly tied into the global fluxes of nutrients and energy, not least through its highly intensive animal husbandry production, which even today in postindustrial society constitutes a significant fraction of GDP. Thus, agricultural acreages constitute 66% of the landmass and while the waste from human population sources is currently 5.3 mio. PE, the human equivalent from animal sources is close to 140 mio PE (Wrisberg et al., 2001). While local plant production systems largely service the animal production output (mainly milk and pork), they are far from sufficient to sustain animal production systems at current levels, so large amounts of fodder is conveyed from global exporters of soybean, cassava and a number of other high protein and energy sources of plant produce. Locations similar to Denmark can be found in other parts of Europe, the US, and more recently Southeast Asia, but they constitute global extremes in an ecological sense. One might naturally question how it is possible to improve management in so distorted systems where, as in Denmark, seminatural patches of land are strongly influenced by gaseous deposition of, e.g., N (20–30 kg N per ha$^{-1}$ yr$^{-1}$). In our analysis it would not be relevant to return nutrients recovered from urban areas to local natural (oligotrophic) systems, since such are very few and far between, and are held very dear to society with strong protective measures. However, as the current lay of the land is, many stockless farming systems can be found in the vicinity of urban areas, in which mineral fertilizers are used quite regularly and can be replaced with ‘urban fertilizers’ if these have an acceptable quality.

Thus for us, choosing the ‘recycling to peri-urban agriculture’ is the only option, if we want to decrease pressure on the local water bodies and increase recycling. In other parts of the world it might be possible to choose other paths for recycling including return to natural systems (e.g. wetland systems), but as a rule a low input agricultural system would benefit substantially from increasing nutrient return (Færge and Magid, 2001; Refsgaard et al., 2006).

From the above results it seems possible to manage recirculation from urban to rural areas technically, with a moderate increase in capital and running costs. Obviously, while the designed systems are based on well known technologies, they have not been tested sufficiently in an integrated fashion. This leaves uncertainty about the actual capital and running costs and user acceptability, which can best be addressed by a gradual R&D effort. If it is generally perceived as desirable to increase recirculation of nutrients, organic matter, and grey water there are a number of obstacles that need to be surmounted. One key question is which driving forces may be harnessed in order to support such a development. In Scandinavia today three types of driving forces interacting to a varying degree can be identified: (a) Private initiatives based on ideals of sustainable housing development, from single family solutions to larger groups (100 family solutions) with little or no external financial input, (b) public initiatives (in Sweden) supported by government and building
4.1. Will farmers accept and utilize the nutrients?

In Denmark, agriculture is currently absorbing approximately 60% of the sewage sludge currently based on contractual agreements with the municipalities, often mediated by third party contractors that address the distribution of the waste products. The remaining 40% is unable to meet the requirements for agricultural use, and is mostly incinerated. The Danish organic farmer association originally sparked the debate on the acceptability of use of sludge being of mixed and indeterminate origin, by refusing to use it in their production systems, and spurred the interest in looking into ecological sanitation and waste management practices which have formed the basis for the current work.

In connection with the present study, several workshops with farmer and other stakeholder representatives were held, in order to uncover the main differences in perceptions. The organic farmers generally favor the use of human urine in food production systems (personal communication Knud Erik Sørensen, Chairman of the Organic Farmers Association) and use of composted fecal and municipal sorted waste in non-production systems, although some are ambivalent to use of urban fertilizers as such. It was repeatedly stressed that the recirculation of resources from urban areas must be done in a safe and hygienic way, which must not undermine the general perception of the organic farming system integrity, and that this type of recirculation should not be seen as a ‘trademark’ for organic farming specifically but for agricultural systems in general.

Practical experiences from KVL’s experimental farm on which there are trials with regular use of human urine, from diverting toilets delivered from eco-villages for experimental purposes, may be revealing: initially there was much debate and some resistance among the personnel and a number of meetings involving authorities regarding the safety procedures were taken. Today there is no such animosity, and the farm hands that are practically responsible for the distribution take pride in it, and claim that they favor this manure strongly in comparison with centralized sewage sludge.

4.2. Drivers for change from conventional to ecological sanitation?

4.2.1. Sustainability

The concept of sustainability used in its broad, holistic meaning implies that sustainability includes biophysical, economic, social, cultural, institutional and political aspects of an activity. Adding to these dimensions of sustainability, the dimensions of time, scale, and values makes the concept more complex and multidimensional. According to the Brundtland approach, an activity has to be sustainable both for the present generation as well as for future generations (the Brundtland definition of ‘the present generation shall meet their needs without compromising future generations ability to meet their needs’, applies), WCED, 1987. A weaker definition of sustainability allows natural capital (natural resource endowment including life supporting ecosystems) to be substituted by man-made capital (knowledge and infrastructure).

When the project was initiated, ‘sustainability’ was a beacon for government environmental policy, whereas at the end the same government officials were focusing on ‘cost benefit analysis’ as the focal point for policy making, due to a government change.

This fickleness of political winds eminently underscores some of the critical methodological traits in our assessment. In this work, one of the main indicators of sustainability is the energy consumption of the various waste management systems, and we assumed that energy conserved would be of equal value regardless if it was saved by mineral fertilizer substitution or reduced system consumption, and therefore translated this as an economic saving during the costing of the systems. This would be in compliance with an Ecological Footprint Analysis approach (Wackernagel and Rees, 1996; Rees, 2000) to the characterization of system sustainability, but in disagreement with the currently favored CBA techniques, which discount environmental costs outside the region of immediate interest, assuming that this is included in services that have been paid (e.g. mineral fertilizer). Similarly, considerable ethical and cultural value was ascribed by policymakers to systems that were better able to conserve and recycle resources, whereas currently this is considered to be of very minor consequence let alone value per se.

Thus, it would seem that basing a development of more ecologically sustainable waste management solutions on political vision and good will may be uncertain in the longer term, unless it can become more strongly institutionalized.

4.3. Private initiatives

A group of people decided to build an eco-village incorporating many of the ideas that were developed in the process of the projects execution. This has resulted in the building of 100 houses located in the vicinity of Copenhagen (Munksøgaard, www.munksoegaard.dk) that have been in great demand and of increasing monetary value from the day of the final development. This project was entirely based on private capital and the ordinary public support that follows certain types of building societies. Perhaps private initiative could be an important driver in itself, even in the larger scales needed to underpin actual R&D efforts of system integration.

4.4. Economic drivers

Finally, an important driver could be economic necessity by itself. Proponents of recirculating waste management schemes frequently claim that once organic waste is removed from the main stream, and similarly nutrients and organic matter are removed from the sewage water, it opens up development of many cost-effective solutions for recirculation of the residual waste, and that therefore it is patently wrong to attribute the costs of the first sorting to recirculation of
nutrients and organic matter on its own, as normally practiced by the CBA proponents. More research will have to be undertaken to accurately assess the cost of implementing ecologically integrated systems.

The developing world, especially the rapidly growing middle-income economies, pose some very interesting possibilities for carrying through on more ecological sanitation and recirculating waste management practices. In the case of Kuching, the capital of Sarawak (Malaysian Borneo), the government has approved an integrated waste management plan, according to which the residential areas will be developed with ecological sanitation schemes, and only in the city centre and business district will conventional sewage systems be built. This decision was based on estimates that convinced the state government that due to local conditions the investment cost of ecological sanitation would be approximately 75% lower than the conventional sanitation, whereas the running cost would be approximately 50% less.

5. 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 world’s 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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