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Integrated Project
Global Change and Ecosystems

D 4.1.7 Current and future transport systems for ecosan products to agriculture, including guidelines and potential for involvement of SMEs

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SWITCH Deliverable Briefing Note

SWITCH Document 4.1.7 entitled **Current and future transport systems for ecosan products to agriculture, including guidelines and potential for involvement of SMEs**
Audience This document is written for the learning alliances in the various SWITCH cities, policy makers and organizations interested in implementing new sanitation systems.
Purpose This deliverable explores how transport can be arranged in new sanitation systems. The first part provides an overview of different transportation systems for source separated wastewater streams for new sanitation concepts. The second part deals with the question 'what happens if' new techniques such as greywater recycling, the black water loop, or other techniques of new sanitation concepts are implemented into larger cities using the SWITCH city Hamburg as an example.
Background Our current wastewater systems are largely based on sewer transport. New sanitation systems based on separation at source require new transport systems. Chapter 1 distinguishes two main situations. One with a need for a new system (while use of existing structures/ infrastructure might be possible) in a rather short time frame (called here Category I), the other on (called here Category II) with an existing established system with need of stepwise modification with a time frame that is compared to the first one rather 'medium to long'. Chapter 2 deals with three different scenarios of a truck-based pick-up system of black water respectively black water solids. Focus was set on energy, space, and emissions, describing the overall environmental impact.
Potential Impact Transport is still a key constraint for the wide scale applicability of ecosan concepts. The deliverable provides insights how transport within these new sanitation systems can be arranged and provides direction for further research and development.
Issues The scenario study in chapter 2 shows that, while pick-up collection from individual households will become very labor and cost intensive, a combined system based on pressure-piping to collection stations and from thereon wheel-based transport can be favourable and applicable. Key point is the volume because of dilution of toilets wastes with flush water. Volume reductions, either by solid-liquid separation techniques or by the use of extremely low flush or even dry toilets will allow for an equivalent reduction of transportation.
Recommendations More work in needed on the interaction between innovative, water-saving toilets and the related transport systems that ultimately bring ecosan systems to agriculture. Technological development in this field should preferably take an integrated, overall look in developing systems, instead of focusing on separate elements.

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1 Transport and Logistics basics in the context of new sanitation concepts

Keywords: transport systems, logistics, ecological sanitation, new sanitation systems

1.1 Abstract

This paper gives an overview of different transportation systems for source separated wastewater streams from new sanitation concepts. The basics of a truck-based system are discussed a bit more thorough, since they are rather new in the context of implemented sanitation systems in larger scale.

In general in this paper two main categories for sanitation are distinguished. One with a need for a new system (while use of existing structures/ infrastructure might be possible) in a rather short time frame (called here Category I), the other on (called here Category II) with an existing established system with need of stepwise modification with a time frame that is compared to the first one rather 'medium to long'.

1.2 Introduction

The two main objectives for the development of new sanitation are on one side the urge to reach the MDGs regarding water and sanitation. This means the need for save water and sanitation has to be halved by 2015, which involves in the case of sanitation at least 400,000 new systems a day (*Mara & Alabaster 2007*), mainly in developing countries. On the other side we want to gain a more sustainable approach in regions, where water distribution and wastewater management systems already are established. For this later case the development of new systems allows additionally the opening of new markets and thus new and positive effects for their economy.

Since these two objectives for new sanitation concepts lead to quite different needs and approaches in planning and since they also require different techniques, in the following it is referred to systems for category I (implementation of sanitation system required) and category II (up-scaling of existing sanitation system). While new sanitation concepts promise solutions in both cases, one of the big challenges in both cases is the implementation of new concepts in larger cities. Herefore many different aspects have to be considered, of which transport and logistics is one.

For the development of each new system positive economics are a strong driving force. To underline the potential of new sanitation concepts, we try to avoid terms as waste. Instead we often speak of products in general (meaning e.g. faecal matter or urine) which can be converted into new products (e.g. fertilizing product). For the generation of each new product raw material (Product A in Table 1) is needed. Between raw material and the later use of the final product, also transport, treatment and conditioning, and distribution are required. A few examples of this simplified setup are shown in Table 1.

Table 1: Examples of a setup of collection, transport, conditioning and distribution of products from new sanitation concepts

Category	Collection system	Product A	Transport of product	Responsibilities for transport structure and treatment	Place of treatment facility	Treatment / conversion of product A into B	Distribution of new product B	Transport of new product B	Final destination of product B
I	dry toilet	feaces, urine	manual	private	on-site	storage of urine, composting of feacal matter	private	wheel based	agri-culture
I	low flush UD toilet	brown water, urine	wheel based	community based	semi-central	brown water digestion or humification	private sector utility	-"-	-"-
II	vacuum UD toilet	brown water, urine	vacuum pipes	private sector utility	semi-central	nutrient extraction, brownwater digestion	-"-	-"-	-"-
II	conventional toilet	black water	gravity pipes	-"-	in-house	nutrient extraction, black water loop	-"-	-"-	-"-
	..	..							

When developing new systems only some obstacles can be predicted while even more will arise throughout the process. In case of new sanitation concepts the need and research for different treatment methods was obvious. At the same time, it became clear, that also the involvement of the users as stakeholder group had to be considered. This is mainly done by integrating them into the process of planning and facilitating combined with information and education. The transport system of products and later on the distribution of possible goods from the new sanitation concepts are now the next step focus is drawn to. Similar to the treatment techniques, available and known methods have to be applied in a new context.

1.3 Transport systems for wastewater and products from wastewater

Transport systems can be differentiated in several ways:

- according to the sanitation system (wet or dry)
- according to the location (in-house, private property or offsite, public property)
- according to type of transportation system

Table 2: Overview of substrate origins and quantities

substrate	*collection system*	*quantity*
blackwater	conv. toilet	4 - 20 lp-1d-1 (dep. on flush vol.)
excreta	dry toilet	1 - 2 lp-1d-1
brownwater	UD-toilet	2 - 20 lp-1d-1 (dep. on flush vol.)
faeces	UD-dry toilet	0.1 - 0.5 lp-1d-1
urine	UD-toilet;	< 0.5 - 1.1 lp-1d-1 (< 40% - 90%)*
	waterless urinal	
		< 0.35 lp-1d-1 (< 40%)**
greywater	kitchen,bathroom	40 - 80 lp-1d-1

* separation grade ~40%, 90% for dry systems
** 50% (male) x 80% (not all) x 70% (not always)

The choice of sanitation system and the location do affect the type of transportation system that can be used. For wastewater generally three different transport systems are possible:

- Piping systems based on gravity
- Pressure piping systems (vacuum and over-pressure)
- 'Dry transport systems' (manually or automated)

In the piping systems (gravity and pressure) water is the medium for transportation. Therefore, these are used nearly exclusively in so-called wet sanitation systems. The transportation properties of water are unique because of its excellent solving properties. For purification of the water or even for reuse of e.g. nutrients these dissolved or suspended substances have to be extracted.

1.3.1 Gravity piping systems

Piping systems based on gravity within houses and gravity sewer systems are the ones mostly used for wastewater transport in conventional wastewater management. The system is characterized by little energy demand for the transport itself, but a need of a certain amount of water as transport medium. Investment costs for the construction and maintenance of sewer systems can be high. Alternative, less costly solutions can be small bore sewerage (*Mara 1996*).

1.3.2 Pressure piping systems

Pressure based transport systems and/or pumping stations are used for wastewater if the gradient does not allow flow by gravity.

Vacuum systems are known from toilets in trains, airplanes, and some new building projects. For longer distances distributions stations can be implemented.

In both cases the energy demand for transport is higher than in gravity transport systems. Investment and maintenance costs are distributed differently form gravity systems but will be also high.

1.3.3 Dry transport systems

In dry sanitation systems faeces or excreta are collected in buckets or bins. Depending on the height of the building toilet and collection bin can be connected by downpipes. Downpipes are normally vertical flow systems. Systems with an angle of 60° are under investigation. Highly organic loaded leachate can be circulated or collected and treated separately. Collection containers have to be ventilated well to avoid odour nuisance.

From the perspective of the users dry systems often are not favoured because of aesthetic reasons (*Drangert 2004*). But with proper design they do have not to stand back behind flushing systems. Dry systems combine the advantages of small volumes to handle and saving water for more important purposes.

In cases where treatment is not conducted at the place of collection transport form the collection place to a place of treatment is needed. Transport systems have to fulfil high hygienic standards to avoid direct contact from people with the collected faecal matter. Thus, most commonly used are containers on wheels with closable lid (Figure 1). In systems with larger distances collection trucks, similar to waste collection are possible.

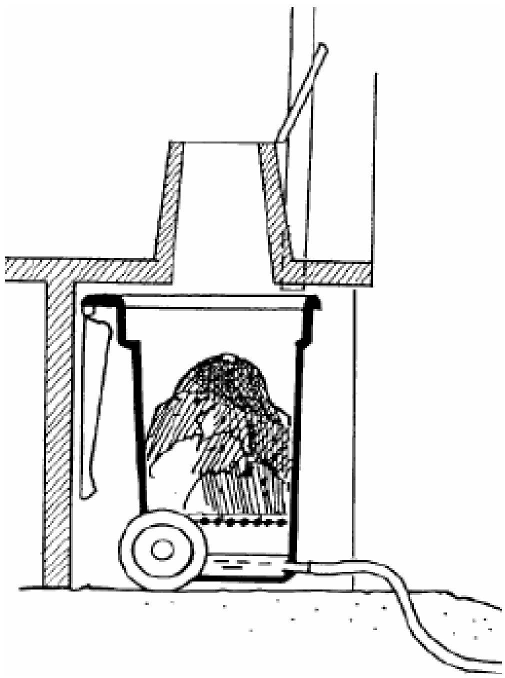

Figure 1: Collection bin for excreta (*Esrey et al. 1998*)

Brown- and blackwater dry transportation system outside of private property can be handled accordingly to the faecal sludge transport via honey-suckers from pit latrines, which is well known and often conducted. With low flush toilets volumes of 5 l $p^{-1}d^{-1}$ can be reached (*Jenssen et al. 2003*) which are not far from common volumes of household waste.

When using vehicle transportation following problems have to be considered and minimized as far as possible:

- Amplified exhaust of greenhouse gases
- Enlarged exhaust of dust particles that can cause smog
- Due to the increased traffic the number of accidents rose
- Blocked streets and traffic jams lead to a bigger loss of time and more emissions
- Higher consumption of energy and especially fossil fuels

Therefore transport operations also have to be optimized in respected to these and following options have to be considered (*Richter, Riedl, & Tiebler 1997*):

- Organisation and management : Environmental Management Systems
- Truck fleet: state of the art (no old equipment)
- Maintenance to reduce emissions and consumption
- Alternative transport vehicles (biofuels…)
- Minimal packaging effort and as light as possible (container, aluminium instead of steel)
- Electronic devices that support truck drivers (GPS, traffic jam warning)

1.3.4 Standards and guidelines for transportation in new sanitation systems

Standards and regulations for the planning and construction of gravity piping systems and pressure piping systems are available for the conventional wastewater management, developed over the last hundred years. Similarly regulations for waste disposal are normally available.

Source separation that is often applied in new sanitation concepts is changing the characteristics of the medium that has to be transported. Therefore regulations for following separated wastewater streams have to be derived:

- Black- and brown water
- Yellow water and urine
- Faeces and excreta (faeces and urine)
- Greywater, respectively greywater and brown water (systems with UD only)
- Stormwater

Volume and consistence influence the efficiency of a transportations system. In terms of transportation black- and brown water do not differ from each other. In-house piping systems for toilet water are known and can be applied. The transport outside of houses with a shallow gradient, especially in cases with low flush toilets, is only able in pressure or dry systems. Yellow water (urine and flushing water) and urine or faeces and faecal matter from dry toilets (separating or non separation) make no significant difference in transport.

1.3.5 Responsibilities for wastewater transport systems

The responsibilities for discharge systems within houses and onsite the private property on one side, and on the other side the discharge systems outside of private property are normally in hands of two different groups with their own regulations for design, realization, and maintenance:

- Private sector
- Public sector (municipality)

In new sanitation systems often short resource loops are yielded for. However, especially with the idea of transporting new sanitation concepts into cities community solutions will often involve also the public sector. Therefore guidelines and regulations for transport of the new substrates have to be developed respectively existing regulations for wastewater transport have to be modified to suit also the products from new sanitation concepts.

1.3.6 Logistic systems

Well planned logistics concepts for any aspect of business help to save money and other resources. Additionally in future sanitation systems different concepts might coexist. Thus, logistic and its processes become even more important, involving all aspects of handling goods and services including storage, transport, and commissioning of those (*Arnold 2004*). The different steps can be divided in four main fields:

- Procurement logistics: how can the raw material find its way to the production site?
- Production logistics: how can the production/treatment be handled?
- Distributional logistics: how can the finished good arrive at the costumer?
- Disposal logistics: how can waste be collected and finally disposed or recylced?

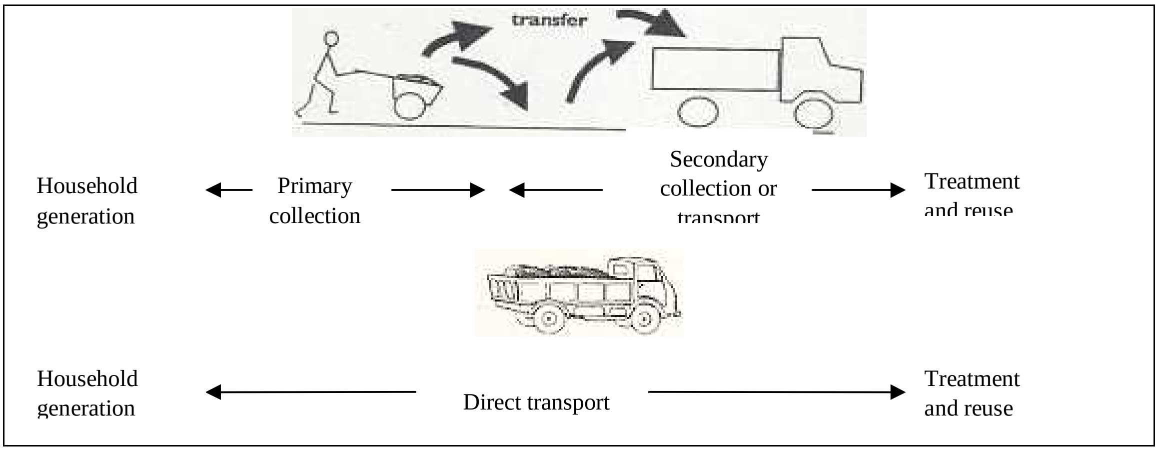

Figure 2: Example of transport with transfer and direct transport

These four process steps can be applied to context of new sanitation concepts, where last one loops back into the first one. Collection and transport logistics can be distinguished depending on how the collection, transport, and distribution of resources and products are organized. Products from source separating systems can be transported directly to a treatment facility and distributed from thereon, or transport and distribution can be spread over transfer stations (Figure 2:). Transfer stations can help to increase efficiency at long distance transport (*Tchobanoglous 1993*). They can also be used for an intermediate treatment step or for storage.

Jenssen and Etnier discussed different aspects of collection and transport of source separation systems and give in Figure 3 a nice overview over some examples of different sewage system infrastructures (*1997*).

Many different options for treatment have been developed, tested in laboratories in first demonstration projects. Some of these techniques can also be implemented in large urban concepts. However, distribution systems of the products are mostly not specified so far.

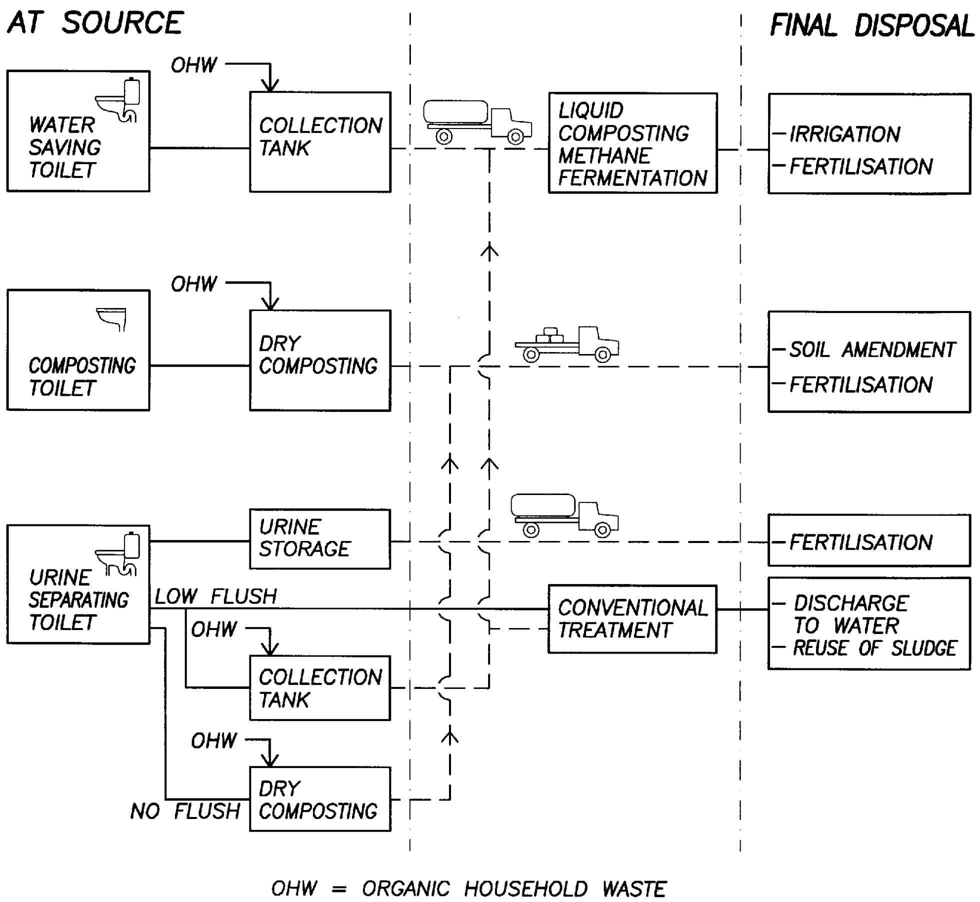

Figure 3: Logistics of blackwater and organic waste handling dependent of toilet type (*Jenssen & Etnier 1997*)

1.3.7 Structural differences of truck-based systems

Learning from what is known already in waste management following factors have to be considered for setting up a logistic transportation system:

- characterisation of waste (density, weight, fractions [biowaste, metals], humidity)

- geographical preconditions (location, altitude, street system…)
- storage container requirements
  this includes volumes, temperature(climate), and substance specific considerations
- location of the pick up (in house, in common storage vessels)

Additionally in respect to the waste following constraints for the pick up service were defined by *Gallkaemper & Bousonville* (*2002*), *MacFarland* (*2001*) and *Bilitewski, Härdtle, & Marek* (*1997*):

- how much should be separated (types of waste or waste water)
- type of container system (in house, in the ground, fixed, movable…)
- frequency of the collection
- full service or partly service (auxiliary activities by the inhabitants)
- amount of personal required
- Quantity to be hauled for present and future loads
- Truck maintenance downtime
- Type and conditions of the roads
- Percent of time when the vehicles will be in productive use
- Residential lifestyle
- Zoning laws and ordinance

The first aspects that should be considered are the number of households that have to be serviced. From the number of households that a truck can service on a single day, the number of trucks that have to be used in total can be derived by by the following equation (*Pichtel, Boca, & Raton 2005*)

$$N = (S \times F)/(X \times W) \qquad \textbf{eq 1}$$

N: Number of collection vehicles
S: total number of households serviced
F: number of collections per week
X: number of customers a truck can service
W: number of workdays per week

Another aspect that has to be considered is the type of settlement structure which has a significant impact on the time consumption of a collection system.

According to *Gallenkemper & Doedens* (*1994*) 5 types of settlement structure can be distinguished:

Table 3: Types of settlement structures and the container density (*Gallenkemper & Doedens 1994*)

Settlement structure	Accommodation unit/ house	Container per 100 m street	Description
1	-		Commercial area with nearly no housing
2	> 6	8.0 – 11.0	Multi family houses
3	> 6	8.0 – 11.0	Multi family houses (3-6 floors)
4	3 – 6	4.8 – 8.0	3-1 family houses
5	1 – 2	4.8 – 8.0	Decentralised housing

The data of this survey are a German urban context. It reflects the clones of houses within the cities.

The settlement structure is needed in order to define how often a truck has to stop in a certain area and how many individual tanks or containers have to be emptied. The population density and the number of houses are indicators for settlement structure. Although with only these data the exact number of multi family house cannot be determined it can give an indication if there are more multi family houses within a district.

The total time of a tour is the sum of driving-time and collection time. The driving-time includes all tours from customer to customer and from and to treatment facility and truck-bas station. The collection time includes all steps of connecting and collection of the product.

For planning a tour and for estimating the time of each tour these different parameters can be combined in the following reduced manner (*Hamburger Abfallbetriebe 2007*).

$$b \times y \times j + t_a + t_s + t_b + t_p + x \qquad \textbf{eq 2}$$

- b: number of kilometres for each tour
- y: time consumption per driven kilometres (speed / Obstacles / traffic lights..)
- j: structure area
- t_a: time consumption for arriving at the collection area
- t_s: time consumption for arriving at the storage place
- t_b: time for breaks which is give by legislation and agreements
- t_p: planning and preparation time
- x: error factor, reflecting occurrence of traffic jams and other delaying factors

The number of tours is given by the volume to be collected and the volume of one vehicle. From these two figures the amount of needed vehicles and teams can be derived. Again, the settlement structure has a major influence on the time consumption. Container sizes, depending on connected houses and traffic situation influence the time of connection & collection.

The distances that have to be travelled to reach every point of a given criterion has now to be minimized, while every house where the container is stored or every place where the waste is taken up has to be included. To improve efficiency also an intermediate storage place can be included. In any case due to minimisation of cost the minimal distance has to be found. In Figure 4 there is a graphic depiction of this phenomenon.

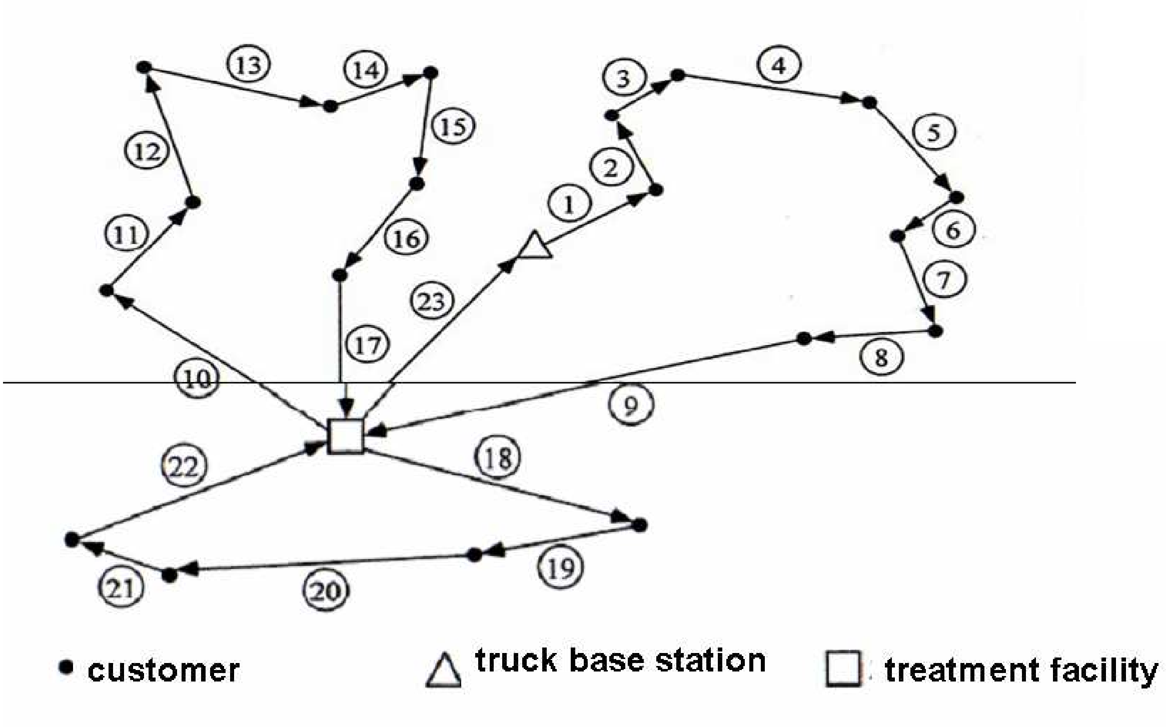

Figure 4: Typical depiction of a touring planning problem (modified from (*Otten & Jünemann 1998*))

For a first approach estimations can be made without using complex mathematical algorithms.

The final goal will be to minimize energy and emissions by logistics. The energy consumption of the transport itself is one of the major factors to be considered. Numbers for energy consumption of the pick-up vehicles vary between 0.35 litres per kilometre up to 1.5 litres per km. The fuel consumption is influenced heavily by age and maintenance status of the vehicles as well as by the driving style. Fuel consumptions e.g. in Hamburg are more towards to lower value due to frequent maintenance and economic driving styles. Emissions from truck-based transport are in the range of 0.33 kg of CO_2 per kWh Diesel consumed.

From these factors effort, energy demand, and emissions of a truck-based transport can be derived.

1.4 System selection

There are a lot of new waste water treatment concepts available nowadays and a lot of them rely on the separation of the conventional waste streams. Important in this regard is the necessity sometimes to treat these streams at different places, which results in a high necessity for transport. More often due to lower investment cost this is considered to be done by trucking, since the small quantities do not always justify the investment into another transport system then trucks. The idea of trucking is especially on a short run an attractive alternative. However, associated with the trucking there appear other problems such as additional traffic on the streets, extra energy consumption and investment in people and machines. For each location individual solutions have to be developed. As stated before the demand can be categorized and is characterized in the following.

1.4.1 Systems for category I

In category I systems are needed that allow reaching hygienic conditions with effective techniques simple to build up, to use, and to maintain. Since the current situation is urgent, the timeframe for implementation is short (5 - 10 years).

As collection systems, also due to more or less temporarily lack of water, dry separation toilets and pour-flush toilets are the choice next to flushing systems.

These types lead to two different transportation systems, independent where treatment will be located: on-site, decentralized, or at a centralized treatment facility. While dry and extremely low flush collection systems need a wheelbased transport (e.g. wheelbarrow / sucking-truck / container transport system), flushing systems of whichever kind allow also a piping system. Regarding a piping system, for category I the conventional sewerage systems has proven to be not the best choice. Investment costs are high, and lack of water will lead to clogging of pipes and thus high maintenance that cannot be served. Small bore sewerage as announced by (*Mara, Sleigh, & Tayler 2001*; *Nance 2005*; *Neder & Nazareth 1998*) proved in some examples transport at less than one half of the costs of a conventional sewerage (*Mara & Alabaster 2007*). While the infrastructure for wheelbased transport is normally present especially in urban areas, transport vehicles and labour is needed over time. Similarly the investment costs of any sewerage system have to be spread over a longer time. The advantage of a wheelbased system is, that it is visible for the user, thus costs for transport are more obvious. Often dry transport systems are already established, since in urban areas faecal sludge from holding tanks is transported by honey-suckers outside the city. Besides of these considerations the conditions present at each individual region will be the driving forces for either the one or the other system. In the end combined systems might be the most reliable ones: wheel based transport for relatively small volumes of sludge, faecal matter, and urine and small bore sewer systems for greywater.

For planning water supply and sanitation improvements for low-income communities, eawag derived detailed principles for urban environmental sanitation (*Eawag 2005*).

Next to choosing the right transport system the responsibilities need to be discussed. For category I there are mainly two different models: 'World Bank consumer model' (*Ruiz-Mier & van Ginneken 2006*) and 'public or private sector utility' (*Mara & Alabaster 2007*). However, according to (*Mara &*

Alabaster 2007) this is not philosophically relevant, although it is recognised that the type of ownership of a water supply and sanitation service provider will have an institutional impact on utility performance and service deliverability especially of poor households. Therefore good regulation is needed.

Since the start- and end-products of new sanitation concepts have different characteristics and their handling yield for different aims, individual transport and distribution systems for product A and B have to be build up. Similar to the organization of the transport system for the 'raw products' (A) of sanitation a transport and also a distribution system of the new products (B) has to be established.

Here, next to the transport and distribution systems, most important are the economical aspects and the question how a flourishing market for products from new sanitation concepts can be established. Besides of market analytics and economical feasibility studies guidelines and standards should be helpful for education, which in the end will be the main driving force.

Target of new sanitation concepts will be a system having the capacities in financing itself by integration of water supply, sanitation and urban agriculture.

1.4.2 Systems for category II

For industrialized countries, speaking of category II, the urgency is mainly not as pressing, thus the timeframe does not have to be as tight as for category I (up to 20 years). Established systems are complex and changes in direction of a new system have to be implemented stepwise. Aims of most new sanitation systems are nutrient recovery and high water savings. Following this, again mainly two different ways of transportation for the products seem most promising. On one side there is again the wheelbased transport, although traffic and air-pollution situation at many places seem not to allow such a system (which is also true for systems in category I). Over long time with new technology such as fuel cell engines and logistic concepts for a decentralized collection at nighttimes, costs should become comparatively to the existing system. Especially because of the stepwise application different systems will have to exist next to each other, which from the perspective of the author might be one of the best solutions anyways.

The distribution system of fertilizer products will most likely be dominated by private companies, but at first its development is highly depending on the market that has to be evolved. For transport and logistics existing structures form recycling products can be used.

1.5 Outlook

The two defined categories can be divided further into subcategories, according to their collection-transport-treatment and -distribution system. Concepts respectively scenarios are developed for some of the SWITCH demo-cities which will also include a more detailed description of different transport and distribution systems. Accra, Beijing, Hamburg, and Lima represent good examples for the defined categories. Thus another stone in the puzzle 'need for solutions in sanitation' will be available.

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2 Transport and Logistics in a context of new sanitation systems -example of a truck based transport of blackwater in Hamburg

Keywords: transport, new sanitation concepts, blackwater,

2.1 Abstract

This paper deals with the question 'what happens if' new techniques such as greywater recycling, the black water loop, or other techniques of new sanitation concepts are implemented into larger cities. While the flush in sewer systems will be extremely reduced (e.g. in Easter Germany total water consumption was reduced within the last 10 years dramatically down to 60 – 80 l/pd), responsibilities for pick-up of high-solid fraction of household wastewater might still be in the hands of one institution, in most cases the municipalities. For the fraction of wastewater with high solid contend other options for transport and treatment need to be investigated.

The paper deals with three different scenarios of a truck-based pick-up system of black water respectively black water solids. For the frame conditions the city of Hamburg, Germany was chosen. Focus was set on energy, space, and emissions, describing the overall environmental impact.

While pick-up collection from household-level will become very time consumptive, a combined system with a pressure-piping system to collection stations and from thereon wheel-based transport seems most favourable.

Volume reductions, either by solid-liquid separation techniques or by the use of extremely low flush or even dry toilets allow an equivalent reduction of transportation.

2.2 Introduction

Generally speaking new sanitation concepts are connected to more different wastewater streams, which means in some ways more transport. But some of this might be unavoidable.

The needs for new sanitation concepts are manifold. One of the main aims is to reach the MDG by UN, to half the need for water and sanitation by 2015. This aim mainly is targeting the dramatic health situation in many regions of the world and means installing 400,000 new connections per day (Mara & Alabaster 2007). The ecological pressure is another big issue for the need of widespread coverage of sanitation systems. While so far mainly inland waterbodies were affected by eutrophication, nowadays also more and more costal areas are changing into dead zones due to eutrophication. This becomes a major threat to the fishing industry (*Pelley 2004*). Additionally the use of many areas for recreational purposes is lost. In all these cases where proper sanitation is lacking new sanitation concepts provide realistic solutions, while conventional systems often failed.

In cases where conventional systems are installed and functioning on a long run economical pressure will require new approaches. Increasing water prices will lead to water savings and partial reuse of separated streams. Sometimes this is already enforced by legislation such as in Beijing, where e.g.

hotels and all other public buildings with construction areas exceeding 20,000 m^2 respectively 30,000 m^2 need their own wastewater reclamation facilities for grey water leading in the end to probably more than 200 million cubic meters saved water per year (*Mels et al. 2006*).

Nowadays membrane technology and its development in the last recent years lead to the assumption that small and achievable treatment units might be available on household-level in a few years. As soon as compact units are available on competitive prices it will be possible to extract large volumes of water for all kinds of purposes, while a considerable fraction of household wastewater solids will remain for disposal. Since new and advanced systems are sometimes considered 'luxury, but nice to have' a wide distribution could be realistic within a short timeframe, once available.

In cases where large quantities of water e.g. in form of greywater or processed water are extracted from the conventional household wastewater for reuse purposes, where rainwater is collected, treated, and infiltrated or reused separately the flushing volume in existing sewer systems can become too low for solid transportation, leading to sedimentation in the system followed by strong odour nuisance. Similar examples can be already observed in conventional systems (*Fischer & Bringewski 2007*). When including toilets with low flushing volumes into this scenario, it can easily be concluded that new approaches are needed. However, in the end these new approaches need to able to be implemented stepwise into the existing systems.

Therefore the transport of volumes with high solid contend such as blackwater or even concentrated black water will be one of the points to be considered for the implementation of new sanitation concepts in larger cities.

2.3 Exemplary vision for Hamburg

In the following three different scenarios of a truck-based transport of black-water will be derived for the city of Hamburg, Germany, and different approaches will be discussed.

2.3.1 Current situation

Hamburg, Germany, has a population of about 1.7 Mio inhabitants. The density is with 2,300 p/km-2 comparable to other larger cities. The total number of buildings is 233,000 while the connection-rate to the municipal sewer system is about 99 %. First parts of the sewer network were built between 1842 and 1890 after a huge fire within the city (*Boeddeker Kommunikation&Medien Hamburg 2006*). The total length of the sewer-system nowadays adds up to 5,400 km. The system is structured into four main sewers with diameter up to 3.5m to allow wastewater transport of 440,000 - 1.2 Mio. m^3/d. The value of the whole water infrastructure per person is about 1,860 €/p.

Water distribution and wastewater management of Hamburg is the responsibility of Hamburg Wasser, companies under unified control. Hamburg Wasser is involved in several projects concerning new sanitation concepts.

2.3.2 Scenarios of truck-based transport of blackwater

For all three scenarios some common boundary conditions were fixed: While parts of Hamburg already have a separate storm water collection system, we assume that in the scenarios rainwater will be separated completely from wastewater and for example dealt with decentralized.

Next to an assumed overall reduction of water consumption main objectives of the future wastewater management shall be maximum energy and nutrient-recovery. Any system would have to able to be integrated stepwise in the existing infrastructure.

For nutrient and energy-recovery a separate blackwater collection (concentrated pollutants and nutrients) and treatment e.g. in biogas plants could be used. Greywater could be collected over the existing sewer system, treated at the central treatment plant, and allowing production of a high quality effluent.

This concept is currently more or less realized in one district in Hamburg under the name 'Neues Wohnen in Jennfeld' respectively 'Hamburg Water Cycle in Jenfeld' by Hamburg Wasser (*Rebbin, Gerbitz, & Friemert 2007*).

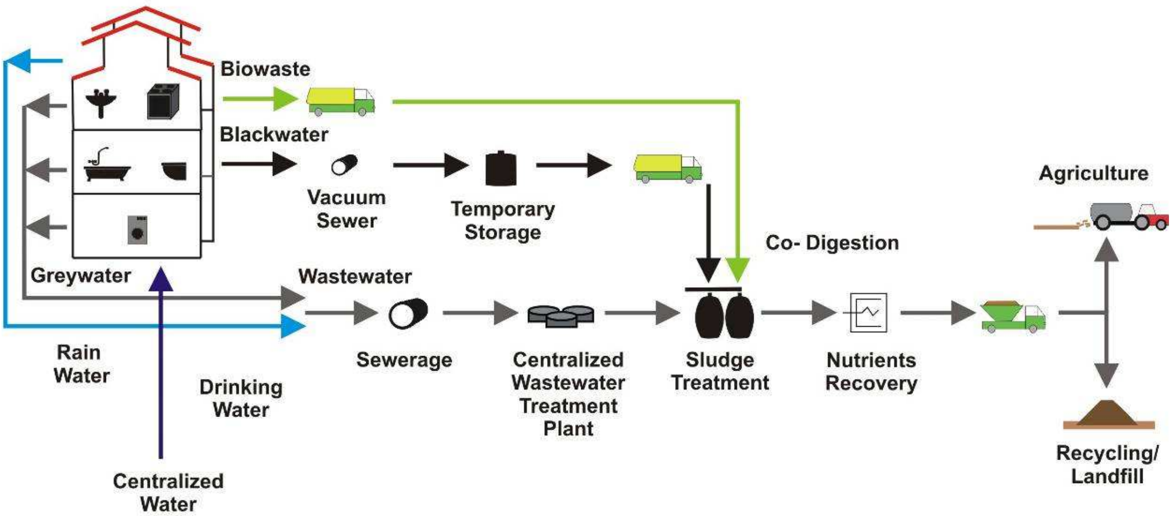

Figure 1: Concept of blackwater collection for biogas production, greywater and rainwater collection in sewer system (Meinzinger 2008)

In the logistic scheme of Jenssen & Etnier (1997) part of this concept (blackwater) is represented more or less by the first example (see Figure 2, red circle). However, the location of the collection tank (length of vacuum piping system) will be one of the parameters, that will be varied in the constructed scenarios.

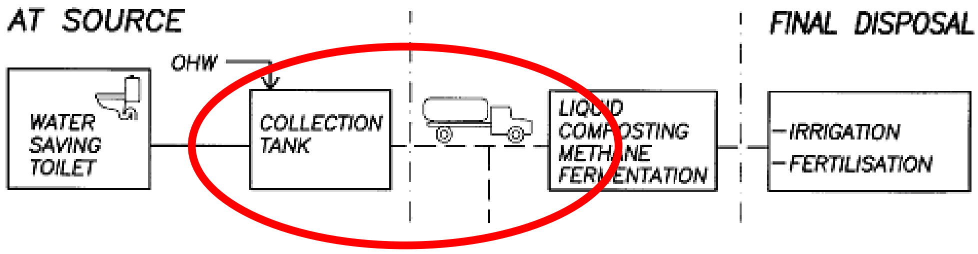

Figure 3: Logistics of blackwater and organic waste handling dependent of toilet type (modified from (*Jenssen & Etnier 1997*)

2.3.3 Model-boundary conditions - data

The data of this work were mainly extracted from the statistical office from the city of Hamburg, and GIS data origin from the transport and logistics department of TUHH. Data e.g. regarding length of streets from GIS, and population density were derived on a sub-district level (see Table 1), as well as assumptions regarding volume collection vessel and others (Table 2). From the length of the street system it can be derived how many kilometres have to be driven in order to reach all locations where the product blackwater has to be collected.

Table 1: Facts on Hamburg - boundary conditions for scenarios

District	street [km]	buildings	apartments	Population	p/km
Altona	638	34.451	119.950	242.557	5.227
Bergedorf	479	19.638	52.760	118.282	2.192
Eimsbuettel	480	29.424	129.793	244.350	5.117
Hamburg-Mitte	640	19.152	116.037	226.747	5.673
Hamburg-Nord	542	29.613	153.653	277.149	7.080
Harburg	788	29.801	91.171	200.322	3.654
Wandsbek	1.007	69.580	196.058	402.957	6.980
total	**4.574**	**231.659**	**859.422**	**1.712.364**	

The street system combined with the population density of each sub-district (ca. 100), and with the amount of source separated wastewater per person leads to the volume that has to be transported and therefore leads to the numbers of trucks required.

For the transport volume of the trucks an average of 16 m^3 were estimated. The volume has a direct influence on the economics and is depending in some areas on geographic conditions.

A realistic frequency of collection intervals was set similar to the current waste-collection to be weekly, to avoid heavy decomposition of the substrate on one side, on the other higher frequencies would increase traffic volumes, as can be seen later on.

Figure 4: Assumptions for Hamburg – four depots for collection and further distribution or for treatment

In respect to the numbers of collection centres different solutions were discussed: A higher number of depots would yield in shorter tour-distances but on the other side leads to a more complex system and higher investment costs for setting up these depots. Very few depots, down to one single depot would cause traffic problems and would require longer driving distances. In respect to the population distribution one depot seemed sufficient for the South of Hamburg (Harburg+Bergedorf). For the sub districts in and around Wandsbek one depot seemed necessary. The amount of people not yet considered would justify only 2 additional depots to have a more or less balanced distribution. Therefore four different locations owned by Hamburg Wasser spread over the city (see Figure 4) were chosen as collection/treatment depots (collection centres). Further transport of generated final products was assumed to be equivalent to equivalent products on the market.

Four different activities have to be considered in tour planning: connection of the truck and the tank, sucking of the wastewater, movement in order to reach every house within a sub-district and the journey from the depot to the sub-district and coming back. Time consumption for sucking was set to be 5 sec, average velocity in the collection area 20 km/h. The time consumption for branching in was estimated to be 120 sec, since the connection hose has to be connected with the transport container. These numbers were derived according to waste-pick-up by Stadtreinigung Hamburg. The average speed for arriving and leaving the collection area was estimated to be 30 km/h.

With a fuel consumption of 35 L/100km cost for diesel fuel were set to be ~ 1.0 €/litre (Shell refinery 30.01.2007), and the conversion factor from fuel to CO_2 is equivalent to 0.329 kg CO_2/kWh diesel. Investment costs for one collection vehicle were estimated to be 180,000 €

Working hours are subject of negations within certain boundaries. In general 37 to 40 h per week can be assumed. For man-time a five day working week with an average of 7.5 hours according to German legislation was chosen. An average monthly salary with additional personal costs was set to be 1800 €/month. These could be much higher depending on experience and age. Per on collection team 1 to 2 staff-persons were set to be required, as long as branching cannot be automatized.

Table 2: Additional factors considered as assumptions

location of pick up (inhouse, storage vessels)
storage container requirements (volume, climate)
geographical conditions (location, altitude, street system)
characterization of waste (density, weight, fraction,…)

The linear distances were combined with a detour-factor of 1.4 to 2 because of high numbers of one-way streets in Hamburg. Costs of 1 m^3 containers were set to be € 100, because of their high number required. For 10 m^3 containers costs of € 2,000 were estimated, because of higher construction costs.

2.4 Analytical method

The previous mentioned data were combined by logical connections. By intersecting the grid of streets with a map of the districts and sub-districts by ArcView it was possible to derive the numbers of streets per sub-district. These data were combined with the length of all streets, the population, and the number of houses. Together with the volumes of source separated wastewater per capita the total volume that has to be collected was calculated. With the volume of the trucks it was possible to determine the number of tours that were necessary to collect to whole volume (see Figure 5).

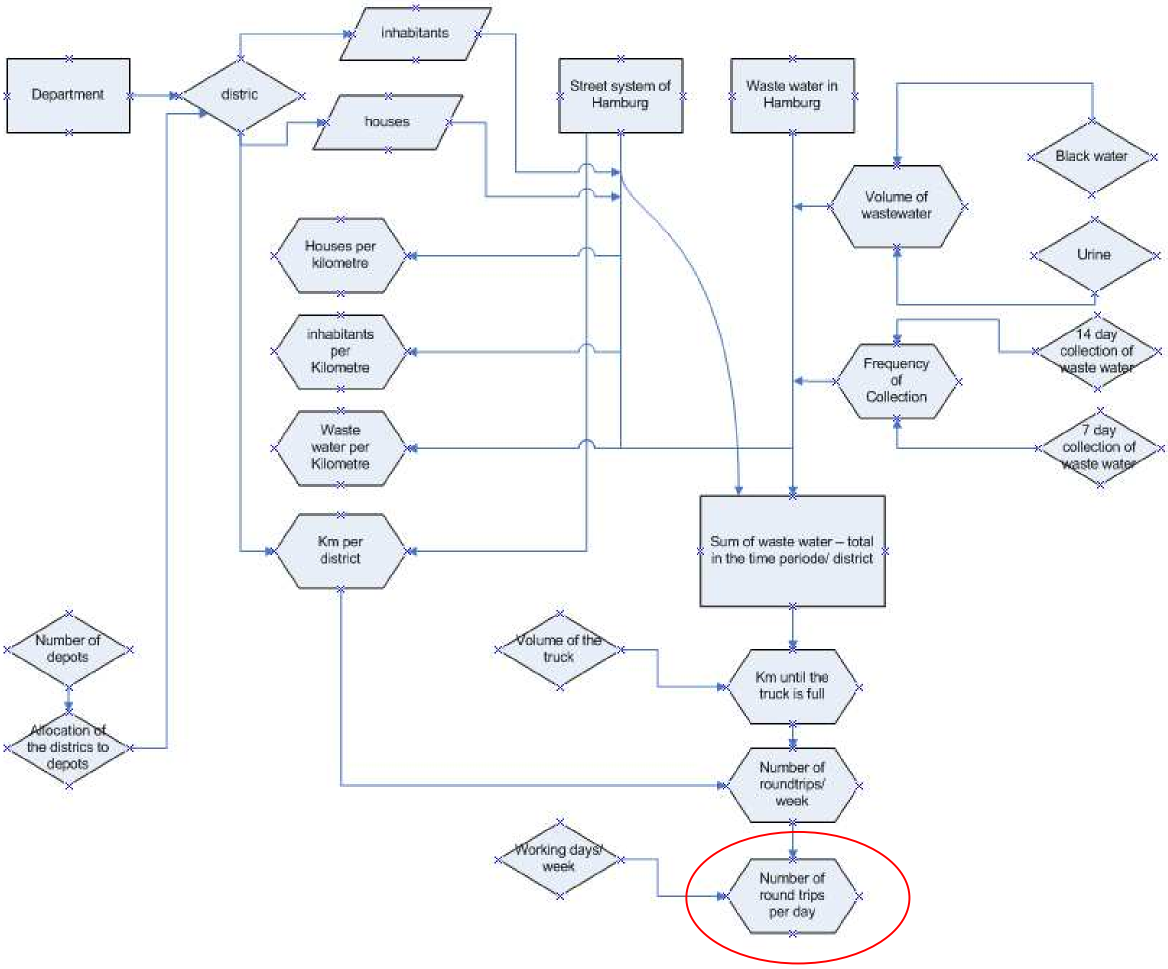

Figure 5: Flow sheet for finding numbers of roundtrip

Beside of the fact of different population distribution (in the inner districts population density is much higher as in the other districts, in the opposite in the outer districts the distances to the collection depot were longer) allocation to the depots was distributed evenly. Through a balanced assigned connection of sub-districts to the depots driving distances could be minimized.

The total time consumption was calculated and divided by the total working time per week. This value gave the numbers of teams that would need to be considered in every sub-district and the number of trucks (see Figure 6). In a last step the environmental load and the fuel consumption were calculated on basis of the driven kilometres.

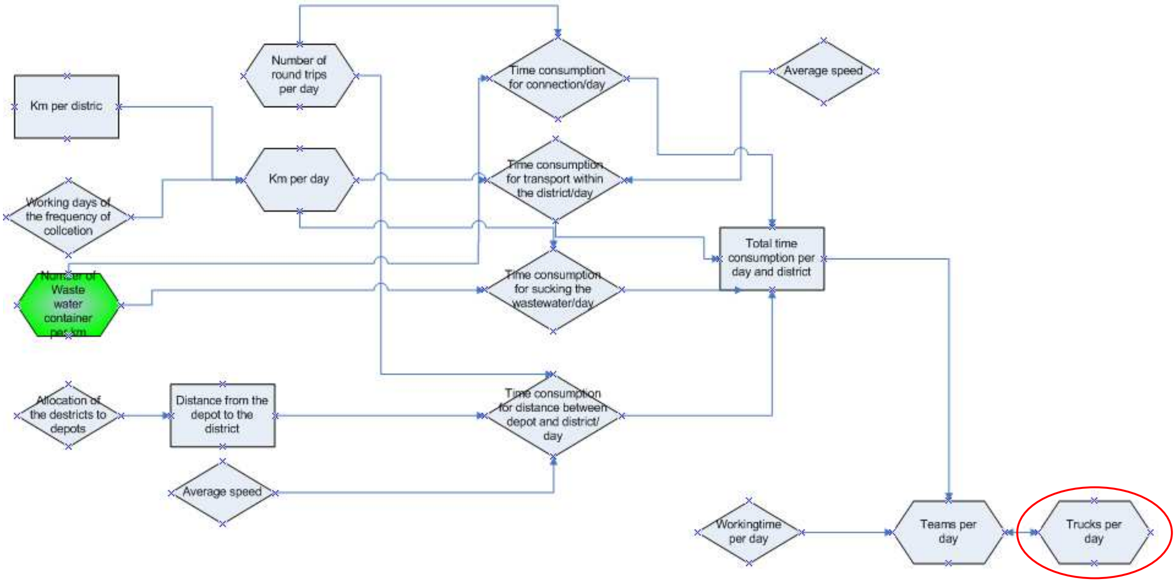

Figure 6: Flow diagram for finding number of trucks required

In Table 3 the main parameters considered in the model of truck-based transport system of source separated wastewater are listed once more, to give a brief overview.

Table 3: Parameters considered in truck-based transportation model

wastewater volume/d
wastewater volume/km
average vessel size [m^3]
km until vehicle loaded
No tours/d
total time per pick up
vehicles/d
people/day
km/week
person costs/month
investment costs for vehicle
...

2.5 Results

2.5.1 Scenario 1

For scenario 1 every house was assumed to have its own collection tank. Therefore each house had to be considered in the tour-planning (Figure 7). For blackwater a volume of 6 litres per person and day were considered.

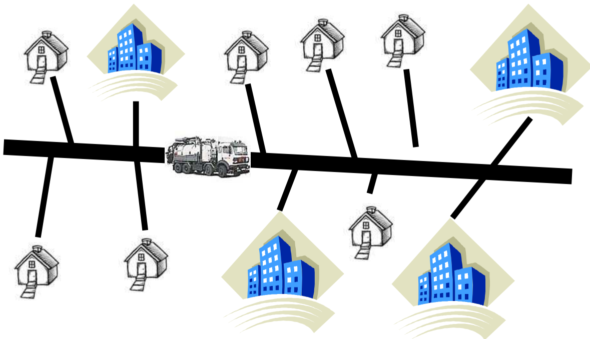

Figure 7: Scenario 1 – storage tank in every building

Table 4 shows exemplary the intermediate results for scenario 1 for the district level. The required container sizes ranged in total depending on the persons per house from 0.1 m^3 up to 2.5 m^3. A total number of more or less 900 tours would be required per day to transport the produced blackwater volume.

Table 4: Black water collection for scenario 1 - 6 l/pd

district	blackwater m³/d	blackwater m³/km	ave.container size [m³]	No tours/d
Altona	1,455	31	0.33	127
Bergedorf	710	13	0.19	62
Eimsbuettel	1,466	31	0.44	128
HH-Mitte	1,360	34	0.61	119
HH-Nord	1,663	42	0.47	146
Harburg	1,202	22	1.03	105
Wandsbek	2,418	42	0.29	212
Total	**10,274**		**average 0.5**	**899**

2.5.2 Scenario 2 & 3

In scenario 2 an average collection container size was estimated to be 1 m^3. Therefore more houses were connected to each container. The planned tour was covering only the collection containers. Blackwater volume was assumed to be 6 l/pd as in scenario 1.

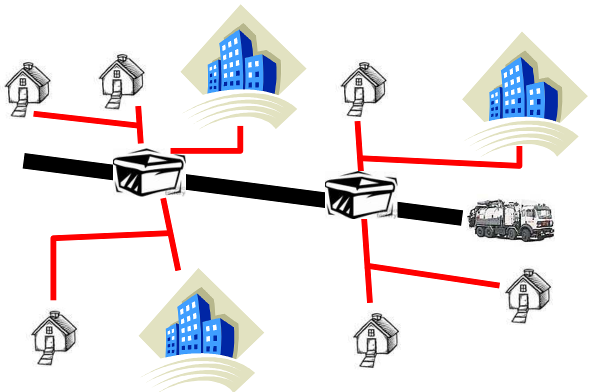

Figure 8: Scenario 2

In scenario 3 an average collection container size was estimated to be 10 m^3. Therefore even more houses were connected to each container. The planned tour was covering only the collection containers. Again, blackwater volume was equivalent to scenario 1 and 2.

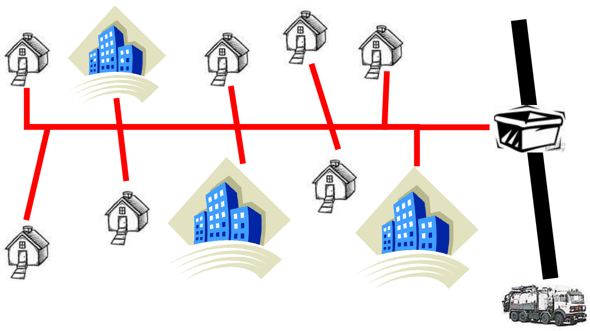

Figure 9: Scenario 3

2.5.3 Combined results

In Table 5 the results in respect of costs and emissions of the three different scenarios are presented. The required vehicles per day varied between 102 in scenario 3 and 310 in scenario 1. Between 200 and 600 persons would need to be employed to allow a truck-based pick-up of 6 litres blackwater per person and day. Since the number of workers is depending on the number of required tours and trucks, the ratio of worker/vehicle is similar in all three scenarios. After about 4 years personal costs would exceed the investment costs of the vehicles in all scenarios.

Although the setup of the model was quite complex, involving many different factors, and although it was derived on sub-district level in the end fuel consumption and therefore CO_2 emissions nearly correlated inverse with the container size. The bigger the containers, the less transport distances were needed. However, the number of needed vehicles and persons showed that because of the large volumes to be transported the numbers of tours could not be reduced dramatically between scenario 2 and scenario 3. This is also reflected in Figure 10, showing the investment costs for vehicles and the personal costs per year.

Table 5: Results black water collection

	collection at house	$1m^3$ collection containers	$10m^3$ collection containers
vehicle/d	310	166	102
p/d	620	324	204
km/week	166,450	75,025	7,500
salary/month [€]	1,116,000	583,200	367,200
salary/year [€]	13,392,000	6,998,000	4,406,000
invest vehicle [€]	55,800,000	29,160,000	18,360,000
costs for fuel /yr	3.059.684	1.379.110	137.865
CO_2 emissions [t/yr]	9.767	4.403	440

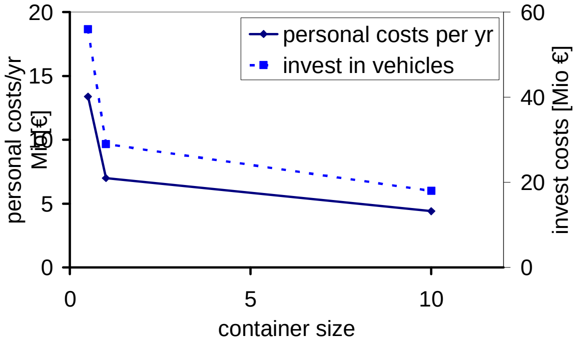

Figure 10: Personal and invest costs of truck-based blackwater transport depending on container-size

The high amount of produced CO_2 is due to the fact that diesel was considered to be the fuel for transport vehicles. It can be assumed that when realizing one of the presented scenarios in large scale other fuel sources could be used. Already today first public-transportation buses in Hamburg are in use with fuel cells and hydrogen as energy source.

Additionally other transportation options could be the network of metro-trains or the canals, that were used in the past for transportation of larger goods. Both options could be included into an extended logistic scenario.

Table 6: Energy output black water collection

	collection at house	**$1m^3$ coll. containers**	**$10m^3$ coll. containers**
energy coverage by biogas from blackwater digestion	25 %	55 %	only 18% of biogas production needed for transport

When considering the energy output, that could be gained from blackwater in biogas-plants (10 norm l CH_4/pd, Table 7) already in scenario 2 more than 50 % of the energy required for transportation could be covered (see Table 6). Co-digestion with biowaste or even biowaste plus cornsilage would even lead to over-capacities in scenario 2.

Table 7: Energy output per substrate

Blackwater	~ 100 Wh/pd
blackwater + biowaste	~ 270 Wh/pd
blackwater + biowaste + cornsilage	~ 860 Wh/pd

Therefore the question of energy demand of a truck-based transport system should not be over weighted. The separate collection of biowaste and blackwater would allow separate treatment with higher energy outputs compared to conventional activated sludge treatment with subsequent anaerobic sludge treatment.

2.5.4 Extended scenario

In an extended scenario it was investigated, how an effective blackwater solid-liquid separation would change the results of above discussed scenarios. In this extended scenario it was assumed to be able to reduce the volume to be transported down to 10 %. This could be achieved by techniques such as the blackwater cycle, currently investigated at TUHH, or filtration-techniques. The supernatant could be reused as in the blackwater cycle or could be transported together with the greywater.

Therefore in this extended scenario it was assumed that only a volume of 0.5 liters per person and day would have to be transported. The sizes of required containers could be decreased dramatically down to 10 to 100 litres, considering a weekly pick-up. A number of 75 tours per week would be sufficient to cover a city of nearly 2 million people (Table 8). Combining an efficient solid-liquid separation on house-hold-level or sub-district-level with larger collection container sizes, would even further reduce the number of required tours, transport kilometres and personal costs (see Table 10).

Table 8: Solid collection

0.5 l/pd	Solids [m³/km]	Solids [m³/d]	km until vehicle loaded	ave. container size [m^3]	No of tours/d
Altona	3	121	184	0.03	11
Bergedorf	1	59	734	0.02	5
Eimsbuettel	3	122	80	0.04	11
HH-Mitte	3	113		0.05	10
HH-Nord	4	139	124	0.04	12
Harburg	2	100	952	0.09	9
Wandsbek	3	201	239	0.02	18
Total		856			75

However, in the scenario with 10 m^3-collection tanks and concentrated blackwater solid separation on sub-district level rather than on household level would allow a well manageable transport in a vacuum-piping system. While for the transport of the blackwater to the collection points the vacuum piping system would have to be extensive, lengths would still be in the range technically feasible, costs for the system would be noticeable.

For better comparison of the first three scenarios with the extended version, the main values of Table 5: Results black water collection) are again presented in Table 9 which can be compared easily with the cost estimation of a solid-transport in Table 10. Especially in case of the scenario 2 the extended version would require only 1/8 of the needed vehicles as in the original scenario with blackwater. In case of required staff 1/15 of the required persons would be sufficient.

Because of the high number of connection points the scenario 1 in both versions do not vary too much due to time consumption for branching to each container on household-level. The biggest difference in costs could be yielded, when comparing the 1 m^3 scenario of blackwater transport (original scenario 2) with the 1 m^3 scenario of solid collection (second of the extended version) due to major reductions in the number of required kilometres per week. Because of the total collection volume these numbers cannot be reduced much further in the extended scenario with 10 m^3 collection tanks.

Table 9: excerpt of Table 5

	collection at house	$1m^3$ collection containers	$10m^3$ collection containers
vehicle/d	310	166	102
p/d	620	324	204
km/week	166,450	75,025	7,500
salary/year [€]	13,392,000	6,998,000	4,406,000
invest vehicle [€]	55,800,000	29,160,000	18,360,000

Table 10: Solid collection – cost estimation

	collection at house	$1m^3$ collection containers	$10m^3$ collection containers
vehicle/d	232	22	18
p/d	232	22	18
km/week	18,100	700	100
salary/year [€]	5,011,000	475,000	389,000
invest vehicle [€]	41,760,000	3,960,000	3,240,000

2.6 Conclusion and outlook

The most important difference between the conventional system with sewers and the new concepts with source separated wastewater streams is the benefit of more efficient reuse, the more effective ability to produce energy, or the possibility to produce fertilizer. At the same time the volume of polluted water is minimized. On the other hand, for implementing a new collection system in an existing context, high investments are required as well as the will for change. The discussed numbers regarding investment are only part of the costs that would be involved, the required vacuum system e.g. was not considered in this study. Additionally to these costs for containers, reinstallation of piping systems, personal cost and maintenance cost would be needed to be considered. The energy consumption would be higher for the truck based waste water pick-up system or other alternatives.

Alternatives such as implementation of flexible hoses into the existing sewer channels combined with pressure systems could be considered. This option could be lower in price, and lower in emissions. At the same time a truck-based system probably would be more flexible. A fact, not that important for a city like Hamburg, but much more interesting for fast growing and expanding cities.

The calculations done were more a good approximation and cannot replace a precise tour planning. Objective was to give a general idea to the efforts and cost that would be required to set up the system. Similar scenarios could be set up for urine collection.

The assumed fuel price is very volatile and it can be expected that the prices will go up even further in the next years due to limited resources. However, alternative energy sources should be able to replace fossil sources. Next to alternative energy sources other transport systems could be included such as the use of existing train-infrastructure, or freight-boats where possible.

Combined systems with decentral concentration stations (e.g. solid-liquid separation) might become an additional option to improve efficiency in transportation in new sanitation concepts.

When aiming for change, also the steps of implementation should be discussed. E.g. office buildings and public events might be an interesting starting point for new collection systems of different source separated wastewater streams. The integration of external processes for process efficiency improvement is also needed to be looked into further.

The current sewer system is not that easy to replace, but with new sanitation concepts small ideas such as ecosan are growing up and offering alternatives.

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