Semi-centralized water systems for rapidly growing urban areas

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Abstract: The rapid development of big cities worldwide leads to infrastructure problems regarding water supply and sanitation systems. Conventional systems cannot keep up with the rapid growth of the cities. In recent years there have been many discussions about alternative supply and sanitation systems, which are to solve the discrepancy between city growth and the demand for supply and sanitation systems. Furthermore, these systems should deal in a sustainable way with natural resources. Different kinds of sanitation systems are discussed, as alternatives for conventional central sanitation systems, so-called "End of Pipe" systems. The existing experience about conventional supply and sanitation systems must be evaluated and new systems must be adapted to the local boundary conditions of future cities. The paper presents a supply and sanitation system (semi-centralized sanitation system) which might prove as a solution for rapidly growing big and also mega cities.

Keywords: rapid city development, big cities, sanitation systems, semi-centralized sanitation systems

Introduction

In the future, modern city planning should put a higher emphasis on the principle of sustainable development than it has done until today. Furthermore, city planning should deal conscientiously with the environment in order to get a higher acceptance on the part of the cities' inhabitants. Infrastructure planning is one of the most important sectors of city planning. Therefore, infrastructure planning should follow the development of the cities (spatial spread) to guarantee efficient supply and disposal services. However, there are multifaceted problems especially in rapidly growing cities, and infrastructure cannot fulfil its duties and responsibilities. Thus, the supply of the city with drinking water, the treatment of waste water and the disposal of waste cannot be ensured.

In this paper, after some facts about future city development are listed, sanitation systems will be introduced in detail. Then so-called semi-centralized sanitation systems and semi-centralized supply and treatment systems are described and compared with conventional centralized and decentralized sanitation systems. Finally, a conclusion rounds off the paper.

Future city development

There are several main reasons which might influence the development of big cities worldwide. Three of them will be discussed below:

- The development of cities is different all over the world. In 1994, only three of the world's 10 largest cities were located in developed countries. By 2015, this number is expected to decline further to two, one will be Tokyo (Japan). However, whereas Tokyo’s population is estimated to increase by less than 5 percent during this period, cities like Jakarta (Indonesia), Karachi (India), Lagos (Nigeria), and Dhaka (Bangladesh) are expected to grow 60 to 75 % [Biswas et al., 2004]. In 2015, from the estimated 27 mega cities - cities exceeding a population of ten million inhabitants - there will be 15 in Asia [cp. Dhakal, 2002].

- There is a difference between the growth of big cities in the developed and the developing world. For example, New York, Paris and London are three mega cities in the developed world. These cities have grown continuously throughout the 20^{th} century. The growth tendency of mega cities nowadays has changed. The development in a gradual process over a long period, such as New York and London, allowed progressive and effective development of the necessary infrastructure systems, e.g. sanitation systems [cp. Biswas et al. 2004]. In contrast, the development of big or mega cities in developing countries is much faster. Therefore, necessary infrastructure development cannot keep up with the rapid growth of these cities.

- Beside the rapid growth of big cities urbanization is increasing, too. In 2000, more than half of the world’s population lived in cities. During the past 30 years, the urban population in developing countries has tripled. Urban areas in Africa, Asia and Latin America are growing with an average rate of one million people per week [Perlman et al., 1998]. Africa has the fastest rate of urban growth in the world. It is expected that by 2025 the continent’s urban population will have grown from 300 million to 700 million or from 30 % to 52 % of the total population [Cross and Morel, 2004]. Developing countries will absorb nearly all of the world’s population increase between today and 2030. The estimated urban growth rate of 1.8 % per year for the period between 2000 and 2030 will double the number of city dwellers. Meanwhile, rural populations are growing hardly at all. Likewise by 2030 more than half of all Asians and Africans will live in urban areas. In Latin America and the Caribbean, at the same time, 84 % of the inhabitants will live in urban areas, a level comparable to the United States [Abhat et al., 2005]. Urbanization in developing countries is increasing, even with declining industrialization and infrastructure and despite fewer jobs and decreasing salaries. Infrastructure development cannot keep up with the rising number of city dwellers. Therefore, the new big cities in the developing world have particular problems with insufficient infrastructure systems.

One result of the rapid growth of big cities is lack of water. The local water demand of big cities is much higher than the availability of usable natural water resources, a fact almost independent from the regions' climatic conditions. The high population density of big cities leads to a great demand for water in a comparatively small area and thus to the exploitation of water resources. Furthermore, because of the rapid city development the lack of sanitation systems and waste water treatment plants leads to additional pollution of the available water resources. Thus, the usable water resources will be reduced twice: (1) by the enormous water demand due to the high population density, (2) by polluting the natural water resources via discharging untreated waste water into the water bodies.

Evaluating the above mentioned facts one may state, that in the future, the improvement of infrastructure systems, especially in rapid growing big cities in the developing countries, is one of the greatest challenges for countries throughout the world. For the development of future cities sustainable and adapted solutions are needed taking into account local boundary conditions. Therefore, future city planning and in particular infrastructure planning in rapidly growing cities are a challenge for all sanitary engineers, sociologists, architects, traffic and transportation engineers etc.

Sanitation systems

The development of future cities and thus the infrastructure is highly dependent on the efficiency of the sanitation system.

Sanitation systems can be classified into three categories. In Tab. 1 three different categories of sanitation systems are listed, which will be discussed below.

Figure 1: Categories of sanitation systems

Category	Description
I	conventional “End of Pipe” systems with a combined sewage system or a separate sewage system and a wastewater treatment plant (WWTP)
II	separate collection of yellow water (urine) and black water (all other water). This system realizes a closed nitrogen and possibly phosphorus cycle without water reuse
III	separate collection of yellow water, grey water (from showers) and brown water (from toilet). This system realizes a closed water and nutrient cycle with water reuse

With conventional “End of Pipe” sanitation systems (category I) waste water is collected in conventional sewage systems (combined and separate sewers) and treated in a wastewater treatment plant (WWTP) – quite often located at the city's borders. In advanced treatment plants the nutrients nitrogen and phosphorus are removed in order to avoid eutrophication of the receiving water bodies. The treated waste water is discharged into water bodies (river, sea, groundwater etc.). Most of these “End of Pipe” sanitation systems are so-called centralized systems. In industrialized western nations these conventional centralized system are very common.

In sanitation systems of category II, waste water from different water flows, e.g. yellow water, brown water, grey water, is collected separately. Yellow water consists of human urine and has the highest percentage of nitrogen compounds of all wastewater flows. Separately collected yellow water can be used - after a certain storage time - as fertilizer in agriculture. Brown water and grey water are not collected separately. They are pumped into a WWTP and discharged after treatment. In this kind of sanitation system water reuse is not realized but the nutrient nitrogen in the yellow water is reused in agriculture.

In sanitation systems of category III, sanitation is similar to category II regarding the collection and treatment of waste water; the water flows are collected separately. Water reuse in this system is realized by reusing the grey water for toilet flushing, garden irrigation etc. Grey water, which originates from showers, wash basins and washing machines, is only slightly polluted waste water, with COD levels < 400 mg/L, low in ammonia, phosphorus and faecal coliform bacteria. No complex treatment process is needed to clean this water. After treatment it can be used as service water in private households or in public buildings, e.g. for toilet flushing, which is approx. 30 % of the total water demand in private households. As a result, the city's demand for drinking water is reduced significantly, thus solving part of the problems of insufficient water supply. Furthermore, due to water and nitrogen recycling, the cycle of water and nitrogen is partly closed. All described systems can be realized as **centralized** as well as **decentralized** systems.

Sanitation systems of category I (see Tab. 1) are normally realized as centralized systems. In centralized systems waste water from all parts of the city is collected, transported in a sewage system, treated in a central treatment plant and is then discharged into the receiving water bodies. Beside domestic waste water the collected waste water also contains industrial waste water. Because of the potential existence of hazardous substances in industrial waste water, the reuse of this water might turn out difficult. A centralized system is designed and dimensioned for a defined period of time. Therefore, the necessary capacity of the sewage systems and treatment plants must be estimated and calculated prior to the planning stage.

Sanitation systems of category II and III (see Tab. 1) can be implemented depending on local conditions. In totally decentralized systems, i.e. within small living communities (about 10 to 1000 inhabitants), the waste water is collected, transported, treated, discharged or reused in each individual house or a relatively small house cluster, respectively. The length of transport units (pipes, sewers) is very short; treatment units are located near the houses, and in the majority of cases the user himself operates the treatment units.

Sanitation systems to be implemented in future cities, must be dependable, economical, and sustainable. Therefore, a flexible sanitation system with a closed cycle for water and nutrients (category III in Tab. 1) will be the preferred system, fulfilling the requirements of future sanitation systems in big cities. Beside centralized and decentralized sanitation systems there is a third system to be mentioned. In the next chapter this system – the semi-centralized sanitation system – is described as a sustainable sanitation system for rapidly growing big cities.

Semi-centralized sanitation systems as a solution for future cities

Conventional centralized sanitation systems are developed using modern process technology, are designed to work reliably and to reach a high treatment efficiency, while fulfilling the economic demands at the same time. In order to transport drinking water and waste water, pipes and sewers of great lengths and large diameters are needed. The mixture of industrial and domestic waste water and the long distances between consumers and treatment plants prevent an economic water reuse [Cornel et al., 2004]. Centralized systems are not flexible enough when considering the rapid growth of the cities in the future; size adaptation is very difficult. These cities need a very high capital investment and have to consider the estimated development prior to starting the implementation of the sanitation systems. Especially construction and enlargement measures cannot keep up with the rapid growth of the new big cities, thus resulting in higher costs compared to big cities nowadays.

The major drawback of decentralized systems is that it is difficult to guarantee constant professional operation and maintenance. The treated water for reuse purposes needs a good quality standard, and the health protection of the consumers must be ensured. These conditions cannot be guaranteed by the operators in a decentralized system (house owners). Furthermore, low-level technology will mostly be used in decentralized systems, thus achieving low maintenance costs and thereby low-cost systems. This may result in insufficient effluent quality.

Semi-centralized supply and sanitation systems encompass the scale of application, responsibility, operation, treatment processes, and scope of reuse. Semi-centralized systems combine both the advantages of centralized and decentralized systems with the avoidance of their disadvantages. Compared to conventional centralized systems, in semi-centralized systems short pipe and sewerage systems are realized, hence the recirculation of water for reuse might be economically interesting. A separation of industrial and municipal waste water is possible, thus relieving the wastewater treatment plant as well. In relatively small areas the implementation of dual piping (for supply and reuse) is feasible, thus allowing water reuse. By using modularization, semi-centralized systems offer a higher flexibility and a better potential for enlargement and adaptation. Due to the larger scale of semi-centralized systems compared to decentralized systems, professional operation and supervision of the treatment systems are guaranteed. Accordingly, semi-centralized systems can keep up with the quality standards of water reuse and consumer health protection.

For future cities the semi-centralized sanitation system concept based on category III of sanitation systems (see Tab. 1) is a progressive and economic system which will offer improved water reuse in urban areas compared to today's centralized systems. With these "Semi-centralized Supply and Treatment Systems" (SESATS, see Weber et al, 2005) an efficient integrated city planning can be realized, including the necessary infrastructure measures. The relatively small service areas for SESATS allow short transport distances between the treatment units compared to centralized systems. The treatment units are situated close to each other. Therefore, the effort for integrating planning, construction and connection of different parts of infrastructure (water supply, wastewater treatment, solid waste disposal) can be reduced, compared to large centralized systems. When applying SESATS, well organized operating teams and systems are required to guarantee the successful and safe water reuse within the city regions.

In Fig. 1 centralized and semi-centralized supply and treatment systems are compared. Centralized systems supply the whole city with tap water and also treat all of its waste water and waste. Semi-centralized systems supply single districts within a city with water and treat waste water and waste from single districts.

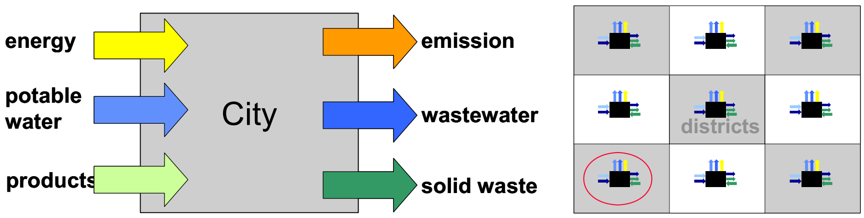

Figure 1: Comparison of centralized and semi-centralized supply and sanitation systems [Weber et al., 2005]

The SESATS - as described above - combine treatment facilities for water, waste water and (organic) waste. These plants also supply service water for household use and intra-urban irrigation for one district within the city (see Fig. 2). Furthermore, because of the combined treatment of organic waste and sewage sludge from wastewater treatment, the production of electrical energy and heat is feasible, which then can be used at the treatment plants themselves or in the neighbourhood.

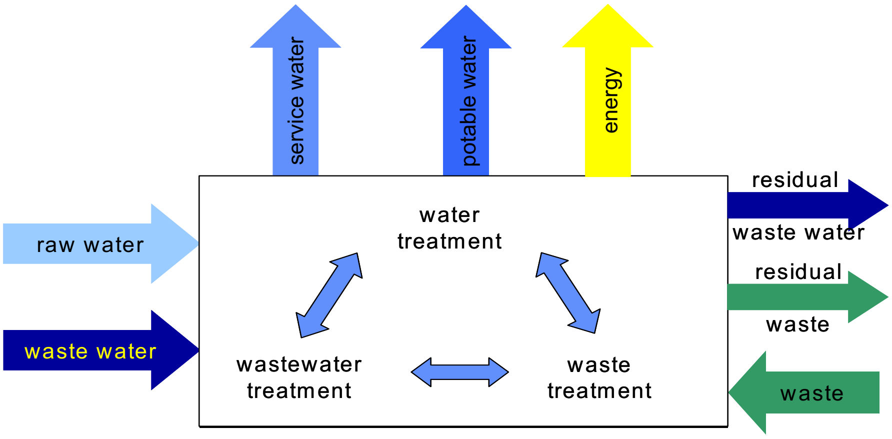

Figure 2: Scheme of one unit of a semi-centralized supply and sanitation system [Weber et al., 2005]

Conclusion

The infrastructure of water supply and sanitation systems is deficient in the majority of the rapidly growing cities in developing and emerging nations. The well developed big cities do not only have problems with insufficient infrastructure, but also with the necessary extension measures and regular maintenance of the current infrastructure. Thus, it is important to evaluate, how the infrastructure development can keep up with the city's rapid growth. The sustainability of city and infrastructure development should be considered in the progress. Semi-centralized supply and sanitation systems, which are based on nutrient recycling and water reuse in relatively small units, may be a suitable ecological, economical and sustainable solution for the big cities. It is not possible to determine a standard size for semi-centralized systems. It is rather necessary to evaluate the size for each big city under investigation, thereby taking into account the local boundary conditions (e.g. population, size of city area) and individual needs.

Furthermore it has to be considered that the spatial, administrative and juridical frameworks of a developing area take serious influence on the optimal size. The calculated size from 50,000 up to 100,000 inhabitants of the 'ideal development size' is based on several model-assumptions which have to be depleted by the actual figures of the actual development area. The specific local and regional parameters determine the recommendable size of the supply- and disposal-area on the one and the choice of the best-possible adopted treatment methods udn techniques on the other hand. Generally it can be acted in consumption that the calculated developing-size from 50,000 up to 100,000 inhabitants is reliable in terms of a guide value or benchmark.

Acknowledgement

The authors want to thank the German Ministry of Education and Research for the founding of the research project "Semi-centralized supply and treatment systems for urban areas in China". This project was the fundament of the present paper.

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Semi-Centralized Water Systems for Rapidly Growing Urban Areas

Prof. Dr. Martin Wagner

Content

- **Introduction**
- **Future city development**
- **Semi-centralized sanitation systems as a solution for future cities**
- **Conclusions**

Introduction

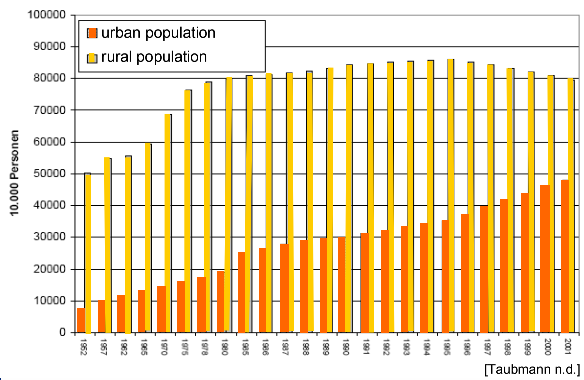
- **in future:** modern city planning should put a higher emphasis on the principle of sustainable development
- **dealing conscientiously with the environment:** better acceptance of the inhabitants
- **infrastructure planning** should follow the development of the cities:

guarantee efficient supply and disposal services

Future city developments

- **development of cities worldwide**
  - more large cities in developing countries
  - by 2015, 60 % to 75 % expansion of the population in large cities in developing countries
  - by 2015, 15 of 27 of the largest cities – with a population of more than ten millions – in developing countries
- **difference of city development in developed and developing countries**
  - developing countries: very fast growth in only some decades
  - developed countries: slow growth through the whole 20th century

e.g. growth-rates of urban population in P. R. China (1962 up to 2001)



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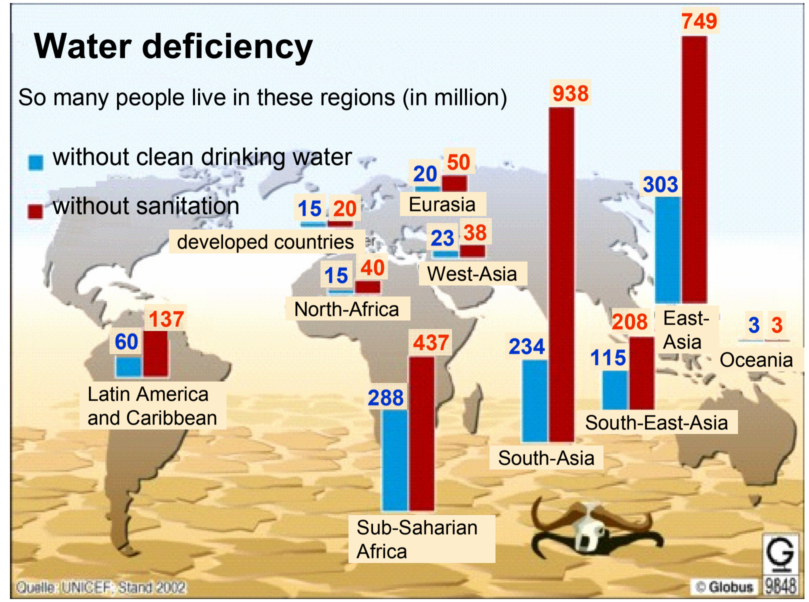
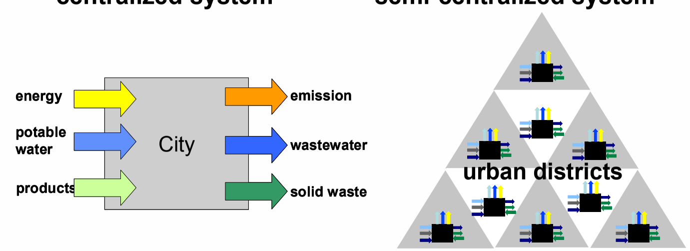


Future city developments

- **problems of cities:**
  - insufficient infrastructure systems
  - lack of water resources
  - additional pollution of available water resources
- **requirements of sanitation systems in future cities:**
  - dependable
  - economical
  - sustainable
  - flexible
- **preferred systems:**
  flexible system with a closed cycle for water and nutrients

→ **semi-centralized sanitation systems**

centralized system **semi-centralized system**



a number of semi-centralized supply and treatment units instead of one big unit

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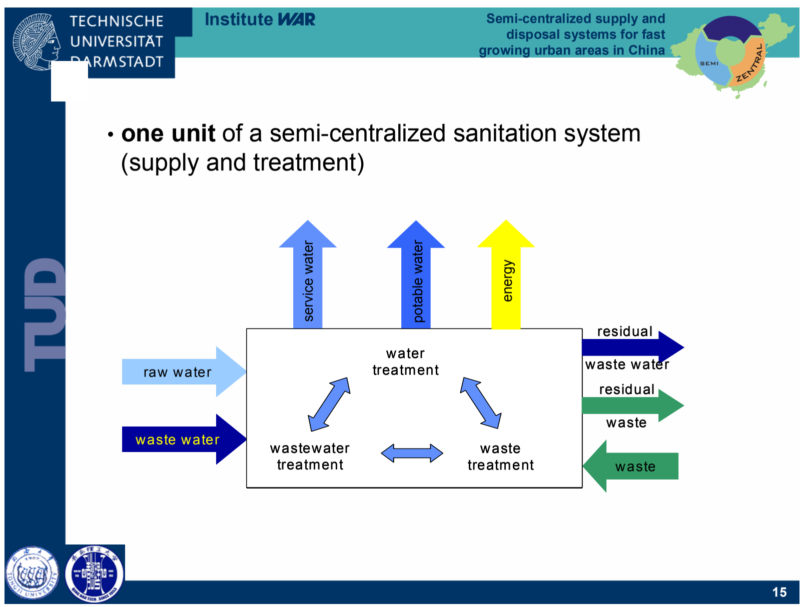
advantages:
semi-centralized vs. centralized sanitation systems

- shorter and smaller pipe and sewerage systems
- **water** (and nutrient) **recirculation for reuse**
- separation of industrial and municipal waste water
- modularization of treatment units
- better potential of enlargement and adaptation

11



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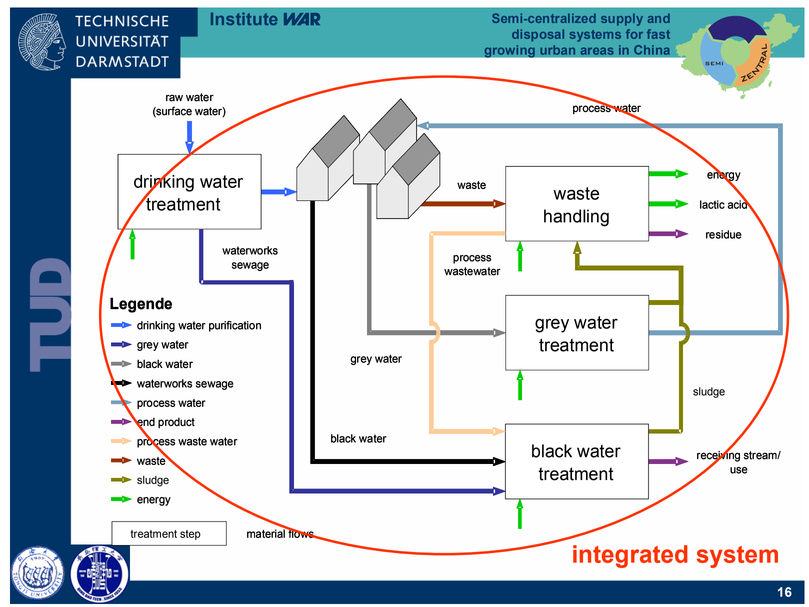
Semi-centralized supply and disposal systems for fast growing urban areas in China
• one unit of a semi-centralized sanitation system (supply and treatment)
service water
potable water
energy
raw water
waste water
water treatment
wastewater treatment
waste treatment
residual waste water
residual waste
waste
TUD
15



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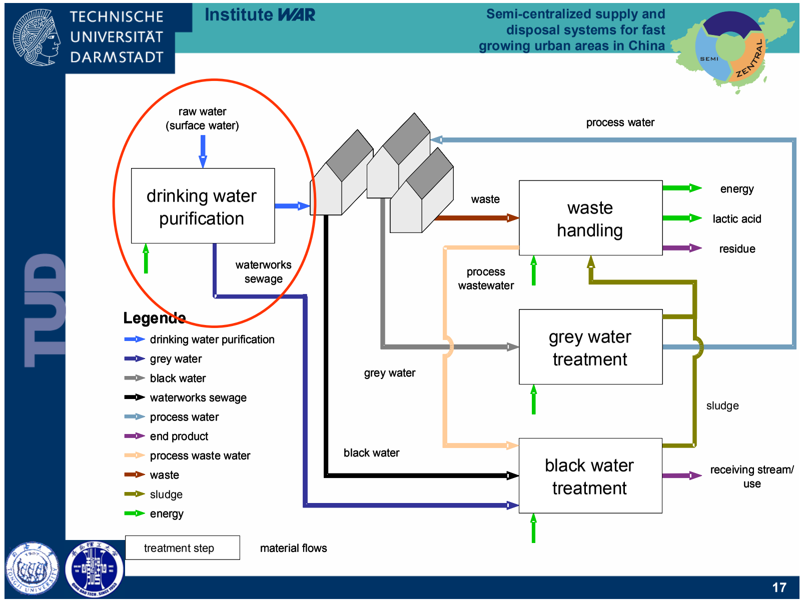
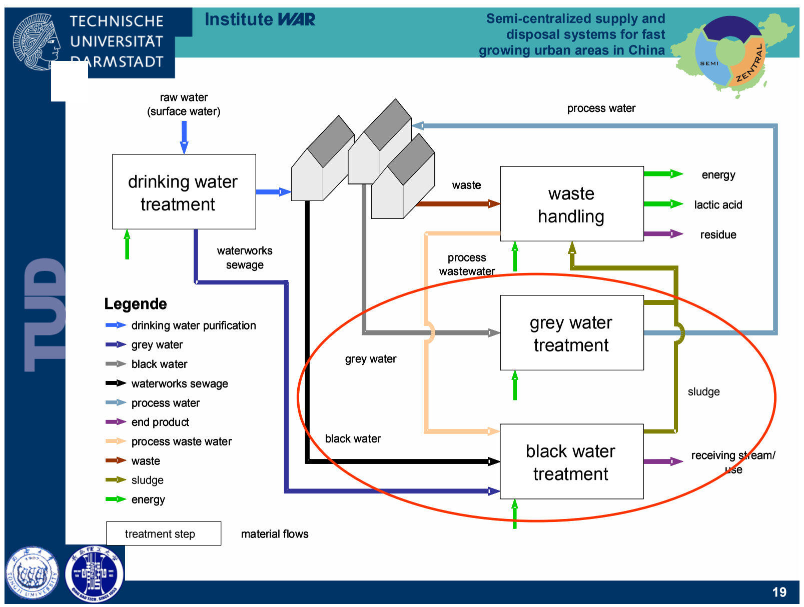
raw water (surface water)
drinking water treatment
waterworks sewage
process water
waste
waste handling
energy
lactic acid
residue
process wastewater
grey water
grey water treatment
sludge
black water
black water treatment
receiving stream/ use
Legende
drinking water purification
grey water
black water
waterworks sewage
process water
end product
process waste water
waste
sludge
energy
treatment step
material flows
integrated system
TUD
16



Water supply

- use of **ground water** is often forbidden especially in urban areas, because of scarce volume problems: underground subsidence, salt water intrusion
- available **rain water** by rainwater harvesting satisfies only a third of the needed amount for toilet flushing, but is useable for irrigation and street cleaning
- because of the reuse of water there is a **saving of tap water**

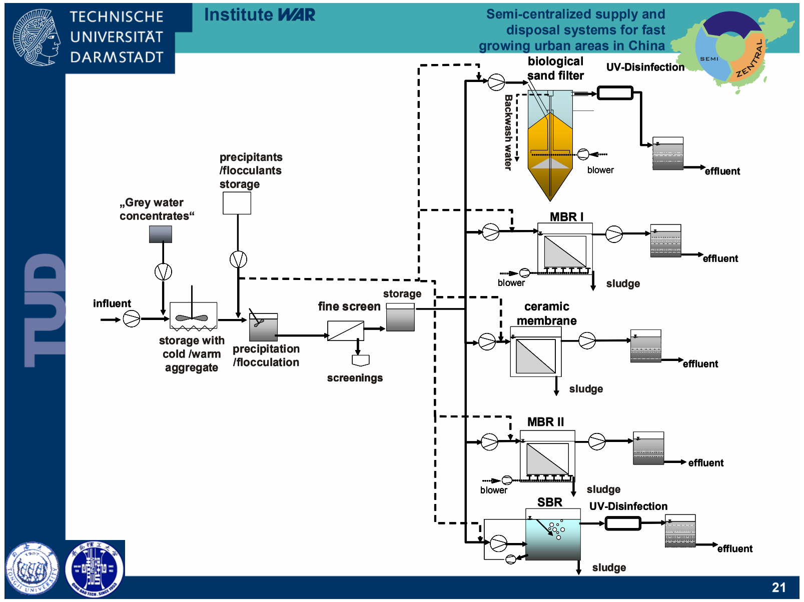


waste water treatment

- **grey water**:
  waste water from showers and bathtubs, hand basins and washing machines
- **black water**:
  waste waster from toilettes flushing and kitchen

after treatment:

- **treated grey water**:
  service water for using in private household or
- **treated black water**: discharge or reuse in urban zones
- **sludge**: combined treatment with residual waste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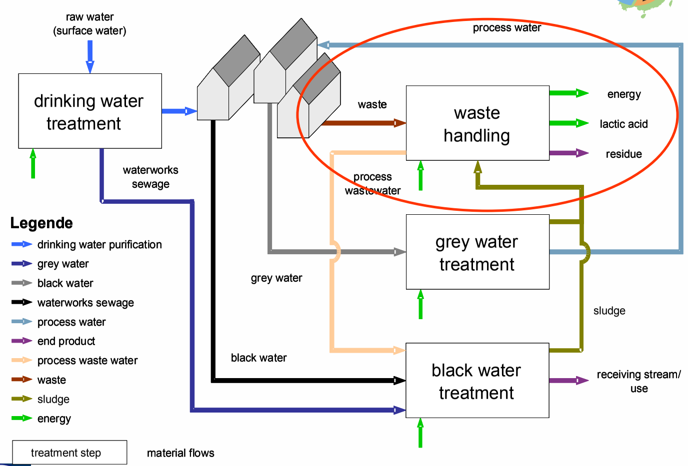
SEMI
ZENTRAL
TUD
influent
„Grey water concentrates“
storage with cold /warm aggregate
precipitants /flocculants storage
precipitation /flocculation
fine screen
screenings
storage
biological sand filter
Backwash water
blower
UV-Disinfection
effluent
MBR I
blower
sludge
effluent
ceramic membrane
sludge
effluent
MBR II
blower
sludge
effluent
SBR
UV-Disinfection
sludge
effluent
21


mixing station grey water
Perwoll
Shampoo

biofilter



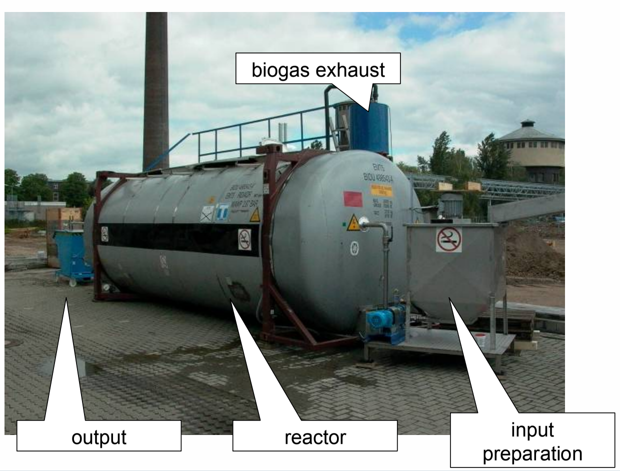
waste treatment

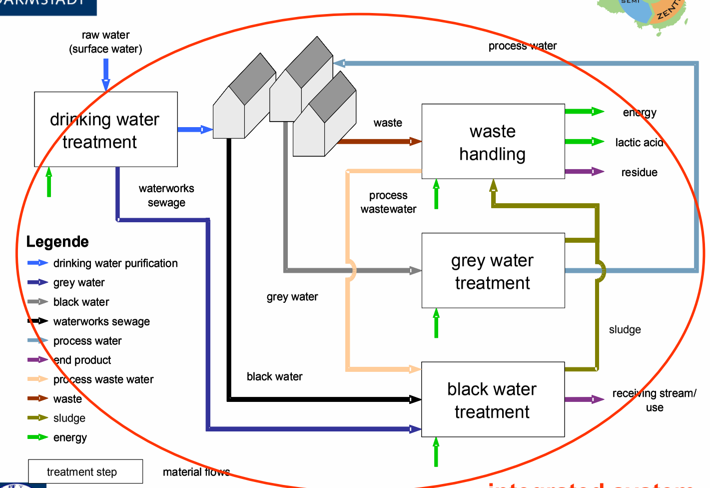
problem: main product of anaerobic waste treatment (thermal energy from the biogas) has no preferable user under the given spatial situation (mono functional habitation)

solution: optimization of process control for the generation of other products, e.g. **lactic acid**. The technology is a combination of classical anaerobic waste treatment and silage production processes

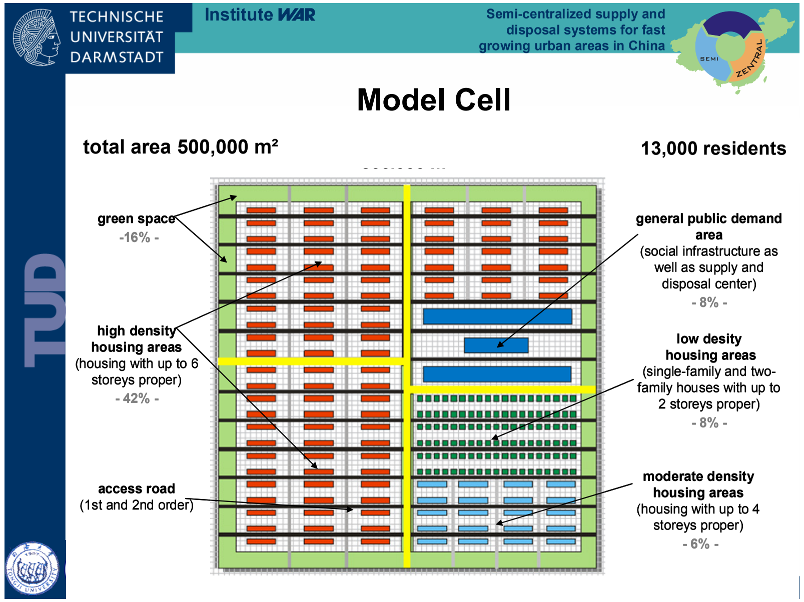
challenges: process control for mono substrates is well known and state of the art technology
in Contrast, organic waste is very inhomogeneous and inconstant in it's composition

Pilot Plant for lactic acid fermentation





integrated system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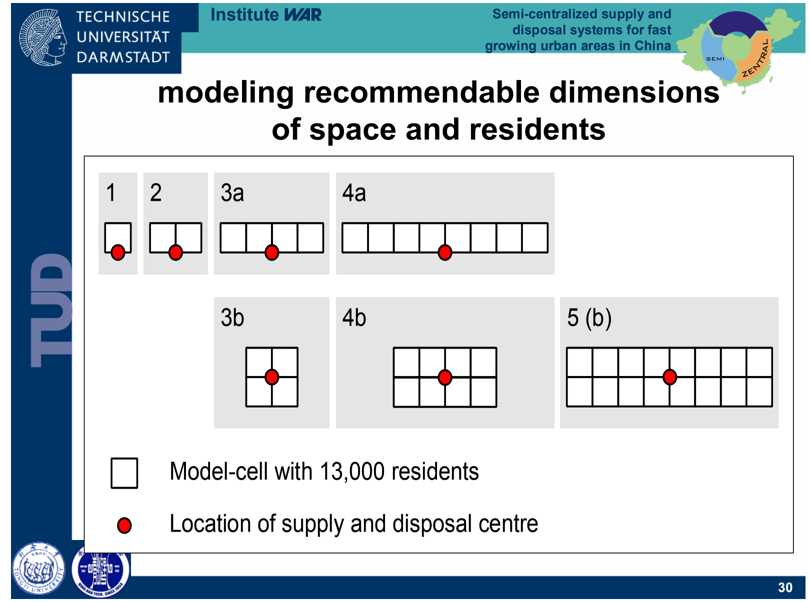
Model Cell
total area 500,000 m²
13,000 residents
green space
-16% -
high density housing areas
(housing with up to 6 storeys proper)
- 42% -
access road
(1st and 2nd order)
general public demand area
(social infrastructure as well as supply and disposal center)
- 8% -
low desity housing areas
(single-family and two-family houses with up to 2 storeys proper)
- 8% -
moderate density housing areas
(housing with up to 4 storeys proper)
- 6% -
TUD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modeling recommendable dimensions of space and residents
1
2
3a
4a
3b
4b
5 (b)
Model-cell with 13,000 residents
Location of supply and disposal centre
TUD
30


Example: City of Qingdao

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Current research status

- integrated supply and disposal systems of a size between **50,000 and 100,000 residents** should be preferred

actual research

- optimising technical concepts
- developing integrated planning and approval processes for integrated semi-centralized supply and disposal systems

34

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Key Questions

- is the idea feasible to make development in fast growing urban areas (more) sustainable?
- are there other strategies to reach sustainability (in cases of supply and disposal systems)?
- what are the challenges in integrated planning and approval processes (for organisational reasons)?

35

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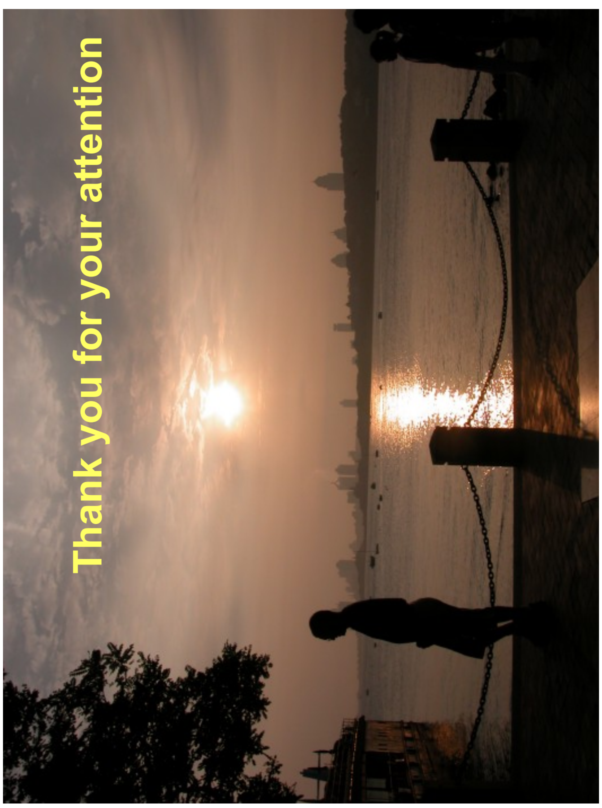
Acknowledgement

Thanks **to the** Ministry of Education and Research of the Federal Republic of Germany **for the founding of the research project** "Semi-centralized supply and treatment systems for urban areas in China".

This project was the fundament of the presented paper

36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