Development, Implementation and Operation of Integrated Sanitation Systems Based on Material-Flows

–

Integrated Sanitation in the City of Darkhan, Mongolia
- A Practicable Example

D I S S E R T A T I O N

zur Erlangung des akademischen Grades

Doktor-Ingenieur (Dr.-Ing.)

an der Fakultät Bauingenieurwesen der Bauhaus-Universität Weimar

vorgelegt von

Dipl.-Ing. Jürgen Stäudel

aus Weimar

Gutachter: 1. Prof. Dr.-Ing. Jörg Londong, Weimar

2. Prof. Dr.-Ing. Dirk Donath, Weimar

3. Prof. Dr.-Ing. Martin Oldenburg, Höxter

Tag der Einreichung: 31.08.2016

Tag der Disputation: 19.01.2017

A f f i d a v i t

Declaration of academic honesty

I hereby declare that I have written the present doctoral thesis on my own and only with the help of the stated sources and resources. Contents taken directly or indirectly from other sources are marked as those. This thesis has not been reviewed by any authority in the same or similar form and has not been published before.

Weimar, 28.08.2016

Jürgen Stäudel

"Nothing is lost in nature.
Creation gives birth to itself
everyday anew in an eternal cycle."

(German original:
"Nichts geht in der Natur verloren,
in ewigem Kreißlauf gebiert sich
die Schöpfung täglich auf's Neue.")

in "*Canalisation oder Abfuhr? - Eine staatswirtschaftliche Frage*"
(Gruber & Brunner, 1871, p. 6)

Acknowledgement

I am deeply grateful to Professor Jörg Londong for supporting me in the process of writing this dissertation. Whereas I doubted many times whether I would be able to finish this work, he always encouraged me and gave me the feeling that I could do it. His advice has often been challenging, but equally precise and guiding in very good and supportive way. His support and friendship means a lot to me.

Further on I want to thank Professor Dirk Donath and Professor Martin Oldenburg for taking their time to assess the outcome of this work. I am really happy that both agreed to support my work. I equally want to thank Professor Eckhard Kraft for hosting me for more than a year and providing the space to work on this dissertation, which was very valuable for me.

I am tremendously gifted by having had the chance to gain insight into the living circumstances of the wonderful people of Mongolia and to get to know their beautiful country. There are countless nourishing moments and beautiful stories, which I will never forget. I deeply thank all my Mongolian colleagues, friends and families of bag7 in Darkhan for their support, their trust and cooperation. I can only name a few people here and I particularly want to thank Gerel O., Ganbaa K., Mr Tserenadmid, Mrs Tsetsegma, Michael and Seegi, Tschimgee A., Batchimgee P. and family, Purev and so many others. Further on I want to thank Romain V. from Action contre la Faim Mongolia for his remarkable support and good friendship. My achievements would have been very little without all these people.

And of course, I want to thank all my former colleagues and friends at the Bauhaus-Institute for Infrastructure Solutions (b.is), namely Hardy, Grit, and Christian from the MoMo-team as well as Ralf in representation of all other team members. They always had open hearts and minds when I was complaining. Their professional advice was always remarkable and I deeply appreciate their support and friendship.

Last but not least I want to thank my family and (most importantly) my parents for their support and love. Without them and the many professional and spiritual teachers I have had, I would not be the person that I am today. Deep bows and love to all of them, even if it is only me who can clearly see them in this dissertation.

I know about the shortcomings and open points of this work, and there is still a lot to do to get a full understanding of this topic and to push it to the state-of-knowledge it deserves. I am glad that I was able to contribute in a modest way and look forward to see further research to come.

Weimar, 19.01.2017

Jürgen Stäudel

A b s t r a c t

The world society faces a huge challenge to implement the human right of *"access to sanitation"*. More and more it is accepted that the conventional approach towards providing sanitation services is not suitable to solve this problem. This dissertation examines the possibility to enhance "*access to sanitation"* for people who are living in areas with underdeveloped water and wastewater infrastructure systems. The idea hereby is to follow an integrated approach for sanitation, which allows for a mutual completion of existing infrastructure with resource-based sanitation systems.

The notion *"integrated sanitation system (iSaS)"* is defined in this work and guiding principles for iSaS are formulated. Further on the implementation of iSaS is assessed at the example of a case study in the city of Darkhan in Mongolia. More than half of Mongolia's population live in settlements where yurts (tents of Nomadic people) are predominant. In these settlements (or *"ger areas"*) sanitation systems are not existent and the hygienic situation is precarious.

An iSaS has been developed for the ger areas in Darkhan and tested over more than two years. Further on a software-based model has been developed with the goal to describe and assess different variations of the iSaS. The results of the assessment of material-flows, monetary-flows and communication-flows within the iSaS are presented in this dissertation. The iSaS model is adaptable and transferable to the socio-economic conditions in other regions and climate zones.

Keywords: *iPiT®, iSaS, integrated sanitation system, balance model, UDDT, extreme climate, participatory planning process, NASS, Mongolia*

Z u s a m m e n f a s s u n g

Die Weltgesellschaft steht der großen Herausforderung gegenüber das Menschrecht auf Zugang zu Sanitärversorgung umzusetzen. Es wird zunehmend akzeptiert, dass konventionelle Ansätze der Abwasserwirtschaft dieses Problem nicht lösen können. Die vorliegende Dissertation untersucht die Möglichkeit eines integrierten Ansatzes, welcher Stoffflüsse, Geldflüsse und Kommunikationsflüsse gemeinsam betrachtet und komplementär zu existierenden Infrastruktursystemen angewendet werden kann.

Der Begriff *„integriertes Sanitärsystem (iSaS)"* wird definiert und anhand eines Fallbeispiels in der Stadt Darkhan in der Mongolei untersucht. Hierbei wurde ein Sanitärsystem für Jurtensiedlungen erarbeitet, pilothaft umgesetzt und über 2 Jahre betrieben. Weiterhin wurde ein software-basiertes Modell anhand der Prinzipien von iSaS entwickelt und verschiedene Variationen des Systems untersucht und diskutiert. Das Modell kann an die klimatischen und sozioökonomischen Rahmenbedingungen in anderen Regionen der Welt angepasst werden und damit die potentielle Umsetzung von iSaS unterstützen.

Schlagwörter: *iPiT®, iSaS, integriertes Sanitärsystem, Bilanzierungsmodell, UDDT, extreme Klimate, Partizipatorischer Planungsprozess, NASS, Mongolei*

Table of contents

List of tables

List of figures

All figures and photos in this work are made or taken by the author respectively, except where indicated otherwise.

List of abbreviations

ACF	Action contre la Faim
aimag	federal state or province in Mongolia
bag7	town sub-district in Mongolia, number 7
BOD	biological oxygen demand
cap, cap^{-1}	capita, per capita
CCC	(dynamic) cost comparison calculation
CD	capacity development
CLUES	community-led urban environmental sanitation
COD	chemical oxygen demand
DEWATS	decentralised wastewater treatment
DSS	decision support system
DWA	German Association for Water, Wastewater and Waste
DWSS	drinking water supply system
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
ECOSAN	ecological sanitation
ger	Mongolian word for the traditional tent of the nomads
ger area	low-income, peri-urban settlements without essential infrastructure
HH	household(s)
IMF	International Monetary Fund
iPiT®	integrated personal innovative toilet (registered trademark)
iSaS	integrated sanitation system(s)
IUWM	integrated urban water management
IWRM	integrated water resources management
JMP	Joint Monitoring Programme of UNICEF and WHO
K	potassium
khashaa	Mongolian word for fence; synonym for fenced piece of land; plot of land
LCA	Life Cycle Assessment
LOI	loss on ignition
MATLAB®	software for numerical computation, visualization, and programming
MDG	millennium development goals
MFA	material flow analysis
MNS	National Standards of Mongolia
MNT	Mongolian Tugrik (official currency of Mongolia)

MoMo2	Integrated Water Resources Management for Central Asia: Model Region Mongolia Phase 2
MoU	Memorandum of Understanding
MUA	Mongolian University of Agriculture
MUST	Mongolian University of Science and Technology
N	nitrogen, total N
NASS	New Alternative Sanitation Systems
NGO	Non-Governmental Organisation
NL	norm litre or standard litre at standard conditions (25°C, 1 bar)
NPK	primary macronutrients
O&M	operation and maintenance
p, p^{-1}	person, per person
P	phosphorus, total P
PE	population equivalent
PPP	public private partnership
ROSA	resource-oriented sanitation
SDG	sustainable development goal
Simulink®	bloc diagram environment for multi-domain simulation and model-based design
SME	small and medium enterprise
SuSanA	Sustainable Sanitation Alliance
SWM	solid waste management
sum	town district in Mongolia
TS	total solids
TVS	total volatile solids
UDDT	urine diversion (or separation) dry toilet
UN	United Nations
UNICEF	United Nations Children's Fund
USAG	company for water supply, sewage and wastewater treatment in Darkhan
UWOT	urban water optioneering tool
WASH	Water, sanitation and hygiene
WHO	World Health Organisation
WWT	wastewater treatment
WWTP	wastewater treatment plant

A Introduction

In this chapter, a short overview of the content and motivation of this doctoral thesis is given. Further on the outline of this thesis is described in order to help the reader to get a quick and complete access to the procedure and applied scientific methods. A brief description of the discussed topics in the corresponding chapters is given.

This dissertation mainly focuses on the issue of integrated sanitation in *developing countries*. The author is aware of the criticism of using the term “***developing country”***, as it may imply a feeling of inferiority for some countries. Given definitions, for instance by the UN or the IMF are not practicable with regard to the content of this dissertation. Moreover, the term is used to refer to countries or regions, where people experience a lack of basic infrastructure services for sanitation. In general, this is the case for most of Africa and Asia, but as stages of development are very diverse (between countries and regions), the term developing country may also be applicable to countries in Europe (e.g. Moldova) or regions within a country (e.g. detached rural areas in Germany).

Parts of this dissertation are situated in Central Asia, as it is developed within the frame of the research project *“Integrated Water Resources Management for Central Asia: Model Region Mongolia Phase 2 (MoMo2)”.*

In this dissertation, the use of the notion **“*sanitation*”** mainly follows the definition given by the World Health Organization (WHO), where *“Sanitation generally refers to the provision of facilities and services for the safe disposal of human urine and faeces. ...”* and “*...also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater disposal.”* (WHO, 2015). In that sense and with regard to more comprehensive descriptions, for instance in (Huuhtanen & Laukkanen, 2006; WHO, 1987), the notion “sanitation” equally includes aspects from the fields of water supply, wastewater treatment and solid waste management.

The notion **“*integrated* sanitation”** extends this comprehension by socio-economic, financial and further aspects of resource utilisation and linkages to adjacent societal fields, such as agriculture, and is elaborated more detail in Chapter B.

A.1 Problem identification

According to WHO and UNICEF as of 2011 almost one third of the world population (2.5 billion people) lacks access to ***improved sanitation***[1]. Current trends show a sharp decline in the proportion of people with open defecation practise (approx. 15% of the world population in 2011) over the last 25 years, but the Millennium Development Goal (MDG) to half the people without access to improved sanitation in 2015 has been missed by 9% or 700 million people according to the 2015 report on *"Progress on sanitation and drinking water"* (WHO and UNICEF, 2015, p. 12)[2]. Succeeding the MDG period, a new goal of 100% access to improved sanitation in 2030 has been set in the definition of the Sustainable Development Goal (SDG) No. 6 in "*The 2030 Agenda For Sustainable Development"* (UN, 2015). It is estimated that more than 700.000 children die every year due to this lack of sanitation and supply of clean water (WHO and UNICEF, 2013).

The burdens caused by and related to missing or un-adapted sanitation and wastewater treatment on the environment are huge. As such can be named contamination of open water bodies and groundwater, greenhouse gas emissions, soil erosion, loss of valuable nutrients (NPK), increasing water scarcity and more.

In contrast the increased supply of the world population with **safe drinking water** (approx. 89% of the world population in 2011 compared to 24% in 1990) seems to be a story of success. However, quality constraints, intermittent availability and an increasing risk of the contamination of ground water suggest, that the achievements are fragile and not sustainable (WHO and UNICEF, 2013). In particular, on-going urbanisation processes and population growth combined with an accelerating climate change will increase the pressure on the available fresh water resources (Borchardt & Ibisch, 2013).

Compared to the global situation of access to sanitation, the situation for waste management can be described as even more alarming. According to (D-Waste, 2012) only an estimated 3.6 billion people had access to ***basic* solid waste management** (SWM). Around 30% (> 660 Million tons) of the annual total amount of produced solid waste remains uncollected or is dumped in dumpsites without any treatment. Not only are these huge amounts of uncollected and insufficiently treated waste a source of severe hygienic problems, but they also have a severe impact on the environment through greenhouse gas emissions, water pollution, air pollution and an increased risk of flooding. While the volume of produced waste is growing at an even faster rate than the urban population (with the highest rates of growth in emerging markets in Asia, Eastern Europe and the Middle East), the urgent need for effective solutions are evident beyond any doubt (The World Bank, 2012).

In summary, it can be said that the current infrastructure systems are inadequate and insufficiently developed to address the various socio-economic, health-related and environmental problems. Additionally, the amount of resources, recovered in a value-added way, is too low. For instance, around 70% of the municipal solid waste worldwide is still neither recycled nor treated, but dumped in landfills (D-Waste, 2012).

The World Bank report "What a waste", 2012 states: "*Poorly managed waste has an enormous impact on health, local and global environment, and economy; improperly managed waste usually results in down-stream costs higher than what it would have cost to manage the waste properly in the first place."* (The World Bank, 2012). Current urban infrastructure systems are not designed in such way to reveal the potential of resource recovery and therefore they contribute to the **loss of resources and money within national economies**.

Still for the SWM sector there is some hope: At least for waste management there is a global shift recognisable towards a more resource-focussed SWM. An increasing number of governments of developing countries follow in their legislation models of circular economy, similar to the German model of waste prevention, reuse, recycling and recovery (D-Waste, 2012; KrWG, 2013). At the bottom of societies in these countries, millions of the poorest people worldwide live directly of the resources, which are contained in municipal solid waste. These people are called wastepickers and they form the lowest level of the rapidly growing informal recycling sector in developing countries. On a day-to-day basis these estimated 1% of the urban population (Medina, 2008) prove that *"**waste is nothing to waste**".*

The legislative bodies often recognise and admit the severe conglomerate of problems caused by missing SWM, wastewater treatment (WWT) and sanitation. They are representatives and followers of the top-down approach. Unfortunately the governments usually fail to execute their own legislation due to different reasons (EAWAG, 2005). Apparently, **there is a gap** between the top-down approach of governments and the bottom-up approach of the informal recycling sector.

Concerning SWM, some governments at least realise that the different waste streams of municipal solid waste have some sort of value and this is reflected in their legislation. On the field of **wastewater treatment and sanitation** the situation is more complicated: In terms of WWT the governments, their consultants and decision-makers usually rely on the sole concept of the conventional wastewater system with sewage line and central wastewater treatment plants (WWTP). They are not aware, that the conventional system for WWT was designed – as an emergency system – in regions of the world with a different set of climatic, socio-economic, legal and environmental conditions.

The transfer and ubiquitous application of the conventional wastewater concept to regions outside of their origin cannot be done without adaptation; sometimes the conventional concept cannot be transferred at all and completely **new paradigms and ideas are needed** to find solutions for the difficult sanitary situation of an affected population. At this point it could be argued, that this is a kind of non-credible perspective, because it might let the industrialised countries stick to the conventional system and would suggest some inferior solutions for developing countries. In fact, this argumentation would be one-sided.

The conventional WWT concept persuades through the high hygienic standard, provides a high level of comfort, is accepted and expected as an indispensable facility for a high living standard by the population. However, in the industrialised countries the limitations and short-comings of this so-called *end-of-pipe technology*, have become obvious since many years (Lange & Otterpohl, 1997): inflexibility, low resource efficiency, high investment and operational costs, ecological deficits.

In regions with a more than 100-year-old history of conventional WWT an increasing number of experts plead for a change of paradigm. In Germany, the discussions among leading experts of the German Association for Water, Wastewater and Waste (DWA) lead to the formation of the notion **N**ew **A**lternative **S**anitation **S**ystems (NASS). The concepts of NASS consider a separate collection and treatment of different material-flows. A significant number of small and medium-scale projects demonstrate new ways to modern sanitation strategies, which do consider wastewater as a source of resources, instead as a form of liquid waste (DWA, 2010). Through the reuse of water as well as recovery of nutrients and energy in a value-added way, NASS follow the concept of the **circular economy**, which is derived from waste management (DWA, 2015).

Certainly, the conditions for the implementation of NASS in industrialised countries like Germany and other states in Western Europe differ significantly from countries like in Asia or Africa. The high degree of connection to wastewater treatment systems - in Northwest Europe above 80% (M. Grambow, 2008) – and **high investments** into the water and wastewater infrastructure with long depreciation times **do not allow for a profound change** of the system in the short-term. Additionally, NASS in industrialised countries follow a more technology-driven approach towards a change, compared to countries with a lower degree of connection.

Certainly, the situation in developing countries requires a different approach. The overall picture in terms of SWM, WWT and infrastructure in general is much more diverse and open. Of course, different climatic and other environmental circumstances as well as low technological development need different technological solutions. But even more the **socio-economic disparities** in most of the developing countries **are huge and** especially **challenging** when it comes to develop infrastructure solutions, which do not only serve an elite of the urban population, but equally include the urban poor and address their needs as well (WSSCC, 2004). Along with the socio-economic disparities come inconsistent and incomplete legal frameworks, institutional weaknesses and corruption and in many cases a low level of education.

Nevertheless, the concept of **NASS may offer some answers** to the complex questions that arise with sustainable infrastructure development in developing countries, **but it has to be extended** significantly to offer satisfying solutions for holistic resource-oriented infrastructure systems.

A.2 Motivation and relevance

Usually in urban centres some sort of WWT and SWM systems already exist. The integration of NASS with existing infrastructure systems has the potential to unify access to sanitation with ecological aspects, resource protection and economic sustainability. In order to reveal this potential, several aspects such as capacity building measures, community participation as well as adapted technological solutions have to be considered.

A lot of different methods and philosophies (including specific technologies), such as ECOSAN (ecological sanitation, ROSA (resource-oriented sanitation), DEWATS (decentralised wastewater treatment), CLUES (community-led urban environmental sanitation), SSWM (sustainable sanitation and wastewater management), CLTS (community-led total sanitation) and others, are already existing[3]. Usually these methods are developed for the needs of a specific target population within a specific context. They follow mainly the intention to present a suitable solution for a particular problem.

They are not particularly created (or used) for designing an overall holistic concept, which combines existing infrastructure with future infrastructure as well as community participation, capacity building, operational planning and further aspects of resource-oriented infrastructure.

In recent years, international organisations, such as the United Nations and other governmental and non-governmental development organisations, have put a lot of effort into awareness raising campaigns about the worldwide sanitation crisis. Often these campaigns referred to the unreachable achievement of the respective MDG (MDG target 7.C, indicator 7.9) of 75% global access to improved sanitation by the year 2015. Since 1990 the sanitation coverage has increased worldwide, however, the situation remains challenging for the growing world population (United Nations, 2014; United Nations Millennium Declaration, 2008).

A large number of pilot projects and investigations of new technologies accompanied the public attention in sanitation. The promotion of hygiene and WASH (water, sanitation & hygiene) activities around the globe helped to create large public awareness, not only in developing countries. However, a significant breakthrough concerning the practical planning and implementation of new sanitation infrastructure is not in sight. Often the stage of the pilot phase of a sanitation project is not exceeded.

Obviously neither technological nor conceptual solutions have been convincing enough to stakeholders, decision-makers and citizens. In fact, projects fail frequently due to various reasons (as will be shown later in this document). Therefore, the number of people without access to improved sanitation remains unchanged on the same high level of 2.6[4] billion people since before the year 2002 (United Nations, 2005a, 2005b).

Apparently, many sanitation projects are not designed in such a way, which allow them to be integrated into an existing framework of a targeted population in order to operate sustainably. The implementation of a sanitation project involves a lot of aspects on multiple, interdependent levels of the society as well as technological expertise, economic and operation respectively. These aspects are not sufficiently considered in many of the current sanitation projects.

Even worse, the way many planners, decision-makers and investors are thinking is still

a.) limited to long-term conventional and technology-driven solutions, which prohibits parts of a population to get access to sanitation at all ***or***

b.) limited to small-scale research or development projects (NASS or conventional) with short-term funding periods and short-term project outcome.

One can argue, that the legal framework of a country needs to provide the guidance for implementing agencies, and in fact many of the countries have reasonable legislation for this purpose. However, national programs and policies on sanitation have limited impact if they are only providing the legal framework without the means (methods for implementation, professional expertise, sufficient budget) for implementation, as this is often the case. As an example the current situation (legal framework and implementation) on the wastewater sector of South Africa is described in (Stäudel, Schalkwyk, & Gibbens, 2014).

The problem remains complex and in summary it can be said, that

- access to sanitation remains an essential issue for human development and sustainability is not yet given.
- conventional wastewater systems are existing worldwide, but are **not able** to offer an overall solution.
- alternative, resource-oriented approaches for sanitation - based on material-flows and value-added reuse - show big potential, but are **not yet able** to offer a solution.
- change of paradigm among planners, decision-makers, implementing agencies and other stakeholders has not yet taken place.

A.3 Hypothesis and objectives

The **lack of integration** into existing structures seems to be one of **the main causes for project failure**. Existing conventional infrastructure can be combined with alternative technologies in an overall system. This might as well enhance the institutional integrity and economic feasibility of a current and future infrastructure system.

A.3.1 Hypothesis

Hypothesis:
An ***integrated sanitation system*** *(iSaS), which is based on material flows, communication, and monetary flows, would help to identify the short-comings of current sanitation systems and reveal ecological and economical potentials by adapting to local circumstances in the most appropriate way. It supports to illustrate planning tasks and to define steps for implementation.*

So far there is no practicable concept for the outline, design and balancing of integrated sanitation systems, which

a.) considers the diversity and complexity of the systems (including the local frameworks and aspects of ecology, economy, culture, society) and

b.) allows for a unified and comparable procedure in planning, implementation and operation.

Such a model should yet be simple enough to provide a practicable guideline for planners and decision-makers respectively and help to illustrate the different tasks and necessary steps that need to be worked on during the implementation of an iSaS.

The motivation of this dissertation and corresponding questions are:

- to develop a general concept of iSaS: What are iSaS?
- to examine the applicability of the general concept of iSaS: Why are iSaS useful?
- to show the principles for the design of iSaS and their practical implementation: When and how can iSaS be implemented?
- to develop a general balance model as a planning tool for planners in developing countries: Why is a balance model needed? How can iSaS be balanced? Who will use the results? How can they be evaluated?
- to show limitations to the general concept of iSaS: Where can iSaS be applied and where is it not useful?

From this general motivation two main objectives can be derived. These two main objectives are discussed in the 2 main Chapters *B. The notion “integrated sanitation system”* and *D. Mathematical model for iSaS based on material, energy & monetary-flows*.

A.3.2 Main objective 1: The notion of iSaS

In a first step the historical and current background of new sanitation systems is examined and evaluated with regard to the potential of iSaS. From there a general definition of the notion iSaS is developed. This includes basic principles of iSaS, such as resource-orientation, material-flow-based processes and others. Interconnected processes based on material flows (technology, ecology), monetary flows (economy) and communication flows are generally described. The later summarizes capacity development and awareness raising.

The interconnected processes can consider different technological solutions, existing infrastructure, legal framework, community-based development as well as other socio-economic conditions. All these different aspects are described with regard to their importance for the creation of an overall concept. Impacts on as-is state, design and planning, and implementation of an infrastructure project are pointed out.

The expected result can be summarized in form of a practical guideline for as-is state analysis of a targeted area or population, as well as recommendations for action (outline) in planning and implementation of iSaS.

A.3.3 Main objective 2: Model for iSaS

The general definition of iSaS is the basis for the general model. In theory, the model includes all principles and components of an iSaS in a simplified but complete and holistic manner.

During the design of the model the problems of how to balance and how to evaluate iSaS in an effective way are the main questions to be answered. For the design of the model the system boundaries are defined, including the identification of relevant parameters for iSaS in developing countries.

The idea is to be able to outline iSaS for a specific location and use the model as a support tool for the balancing / estimation / description of the main material flows, monetary flows (costs and benefits) and communication flows. The later helps to describe the needs for action of involved stakeholders and points out consequences, benefits and trade-off and interdependencies within the system.

In this dissertation, the software MATLAB® / Simulink® is used to create a general outline and calculate a basic model. Visualised results from the software can support the decision-making process ahead of the implementation of a sanitation system.

The model is applied and tested at the practical example of the integrated sanitation system that has been developed for the city of Darkhan, Mongolia within in the frame of the MoMo2 project (see Chapter *C.* Integrated sanitation in Mongolia – the case example of Darkhan).

A.3.4 Focus of this dissertation - system boundary

This dissertation focuses on the development of a concept of iSaS for developing countries only. The general concepts of NASS are used as a basis for the development of iSaS, but are adapted wherever necessary.

NASS (in this case used as a collective term for new sanitation concepts) is a general concept derived from research activities mainly in the last 20 years in Germany and Europe, but not limited to so-called *"developed"* countries (DWA, 2009). The future change of infrastructure systems in "developed" countries through NASS is driven by different reasons compared to *"developing"* countries.

The future trends in NASS in Europe are triggered by a technology-driven renewal and adaption of existing infrastructure (e.g. research projects KREIS (Thomas Giese (Hrg.) & Jörg Londong (Hrg.), 2015) and TWIST++ (Wolter, Hiessl, & Hillenbrand, 2014)). Usually, NASS in Europe do not have to consider parts of a society without access to infrastructure or low standards of supply. Also, the legal framework and the societal conditions are different at this time and would need a different approach. However, the main difference between developed and developing countries in terms of infrastructure is, that the process of transformation in developed countries is remarkably slower compared to developing countries.

Unfortunately, in developing countries the general level of professional expertise and the understanding of the complexity of urban water management is oriented at *"western"* standards and technologies, which are often not suited for their own specific needs. This dissertation examines a way to describe iSaS against the background of developing countries.

A.4 Methods and procedure

Below the used methods and general procedure of the work on this dissertation are described and an outline is given.

A.4.1 Sources of information, material and data

Standard methods, such as literature review, data collection and analysis are used during the preparation of this dissertation in accordance with common scientific practise. Additionally, below some further information is given about the background of this scientific work.

The author has gained personal experience in SWM and sanitation projects in Africa and Asia. This dissertation builds as well on the personal interests and professional experiences of the author.

A.4.1.1 Content and results based on MoMo2 project

The Department of Urban Water Management and Sanitation at the Bauhaus-Universität Weimar has been engaged in a joint research project in Mongolia from 2010-2013. The title of the project is: "*Integrated Water Resources Management for Central Asia: Model Region Mongolia, phase 2* (*IWRM MoMo 2* or MoMo2)". The author has been working as member of the research team in

Darkhan, Mongolia. Many ideas and results from the research in Mongolia are directly influencing this dissertation or have been derived from there.

A.4.1.2 Students thesis compiled at Bauhaus-Universität Weimar

Some data has been compiled and analysed during the preparation of bachelor, seminar and master theses by students of the Bauhaus-Universität Weimar. The students' theses have been mainly compiled within the frame of the MoMo2 project. All the students' theses were written under the supervision of the author. In case, data or ideas are taken directly from the students' theses, it is specified. A list of the students' theses is presented in Chapter *H.2 Source material, documents.*

A.4.2 Outline

The following Figure 1 illustrates the outline of this dissertation:

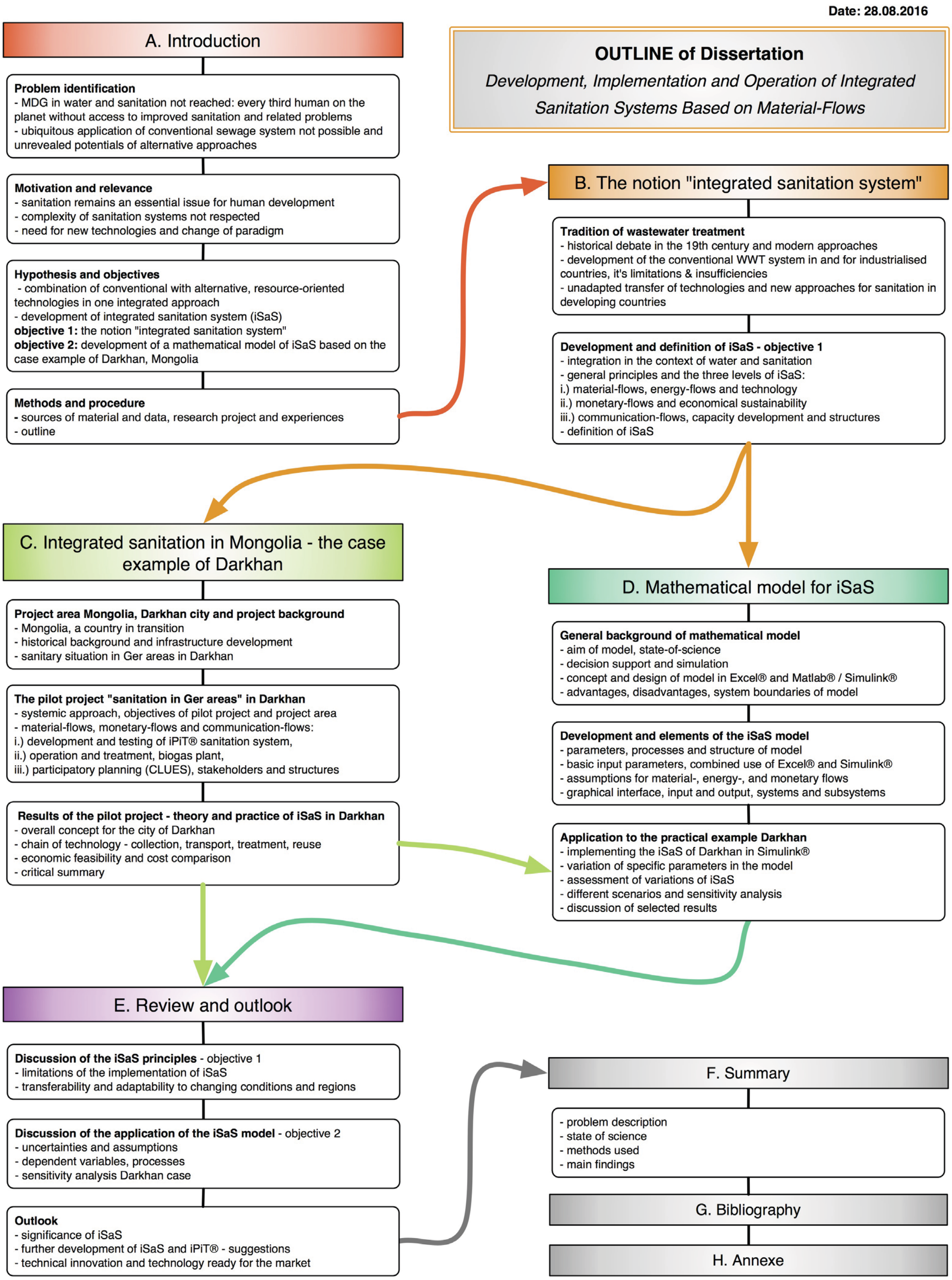


Figure 1: Outline of dissertation

A.4.2.1 Chapter B - The notion “integrated sanitation system”

In this chapter, the historical development (focal point 19th century) of the modern conventional sewage system with regard to current professional discussions and research projects are pointed out. Insufficiencies and limitations of the conventional WWT approach are elaborated. Problems with the adapted transfer from developed to developing countries are described. Consecutively alternative sanitation approaches, such as NASS, ecosan, or CLUES are mentioned, whereas relevant aspects for iSaS are worked out in form of a literature review.

As main objective of this chapter the notion of “integrated sanitation system” is introduced and described in detail. General principles of iSaS and their relevance for the sustainable development of urban infrastructure systems are worked out. The valorisation of all material-flows and their interaction with flows of money and communication are an immanent component of integrated sanitation systems. The principles of iSaS are the basis for the evaluation of the pilot projects in the next chapters.

A.4.2.2 Chapter C - Integrated sanitation in Mongolia – the case example of Darkhan

In this chapter, the pilot project *“integrated sanitation for **ger areas**[5] in Darkhan”* is briefly described as part of the activities of the MoMo2 research project. The focus lies on the description of the sanitation project from data collection to implementation and monitoring.

In a further step an outline of an integrated sanitation system for the whole city of Darkhan is developed based on the results of the MoMo2 project and including the findings of Chapter B. The outline includes the technical system description as well as social aspects, recommendations for administrative structures and capacity development measures, operation and financing of the system.

The general outline of the Darkhan case is displayed further on in the mathematical model and tested in Chapter D.

A.4.2.3 Chapter D - Mathematical model for iSaS based on material, communication & monetary flows

A balance model for iSaS is developed in this chapter case, first in a theoretical manner and in a second step programmed by the use of the software MATLAB®. The balance model shall help to illustrate the general outline of iSaS based on the Darkhan case and reveal shortcomings and benefits of the system.

The model is simplified, but intends to display the iSaS in Mongolia as complete as possible. It should contain the interaction of all technical system components (including collection, transport, treatment, reuse) and non-technical system components (including institutional capacity building, legal framework, operation and maintenance). Interactions with stakeholders and need for action should be pointed out at relevant points within the model. The depth of integration of the iSaS of the Darkhan case and variations of different scenarios shall be evaluated in the model, which includes the flow of contained resources and related costs.

A.4.2.4 Chapter E – Discussion and outlook

The results of the previous chapters are discussed in Chapter E. The testing of the balance model and the theoretical approach of iSaS will be critically reviewed. Further on, apparent limitations to the application of the model will be described and reviewed in a critical manner. Findings and problems are summarised and recommendations for further investigation and necessary technical developments are given.

The transferability of iSaS to different geographical regions is discussed in the outlook. The variety of iSaS due to different technical solutions, cultural background, climate etc with its chances and challenges is discussed as well.

A.4.2.5 Chapter F - Summary

Summary of the dissertation.

B The notion "integrated sanitation system"

This chapter examines the notion "integrated sanitation" and describes a general concept for iSaS. In a first step, historical discussions are put in the present context of conventional sewage systems with regard to the transferability to developing countries. Further on a general overview of the current status of so-called sustainable sanitation projects is given and shortcomings are identified. After that, as one of the main objectives of this dissertation, the basic principles of iSaS are described and the general concept for iSaS is worked out in detail.

B.1 Tradition of the western wastewater treatment concept

The tradition of the modern western conventional wastewater treatment concept is rooted in technical developments, which became necessary in the course of the industrialisation in England in the beginning of the 19^{th} century and some decades later in continental Europe (ATV, 1999).

B.1.1 Development of the conventional sewage system in western industrial countries

Sewer systems are known to mankind since more than 4000 years. They served as drainage systems for storm water and wastewater in the ancient civilisations of Egypt, the Roman Empire, India and others. Aqueducts and water pipelines were used to supply the roman urban population with water over long distances. Reservoirs were used in combination with sluices to provide sufficient amounts of water to regularly flush the sewers of Rome. Human excreta were sold as fertiliser to gardeners and farmers around the city, who supplied the urban population with food (ATV, 1999). In the European Middle Ages, the knowledge about sewers, sanitation and the value (and at the same time hygienic dangers) of human excrements got lost and led to disastrous living conditions in urban settlements over many centuries.

In this regard, East Asia took a different path over the last 4000 years. Sewers have equally been known, but only used for drainage purposes and open canals for irrigation. Faecal matter was collected in cities, transported and reused in agriculture and thus contributed to the preservation of soil fertility over more than 30 centuries (King, 1911).

Upon examination of historic literature, it becomes apparent that the value of human excreta as fertiliser and soil conditioner is well known on all continents since ancient times. This is particularly interesting when looking at modern discussions among experts later in this chapter, as reuse of “human waste” is not an invention of modern times, but has always been practised by intention, depending on cultural, economic and technological conditions. Examples from ancient time to the late 19th century are given in (Strell, 1913), (Dunbar, 1907, pp. 46–61) and (Hösel, 1990, p. 197 ff.).

While in Asia this cultural knowledge has been preserved until the beginning of the 20th century, in medieval Europe it vanished together with a basic understanding of hygiene. The urban population figures in Europe were much lower compared to Asia and cities barely had more than a few hundred or thousand citizens. Europe was characterised primarily rural, which may be a reason for this understanding being less important to individuals and society, or for hygiene has at least not been recognised as problematic.

The situation changed with the deep cultural and societal revolutions in the modern age parallel to the industrial revolution starting in the second half of the 17th century. In less than 200 years the European population more than tripled from 1700 to 1900 (Berlin-Institut für Bevölkerung und Entwicklung, 2014). The rapidly growing urban centres in the beginning of the 19th century led to disastrous hygienic conditions for the citizens and to repeating epidemics like pest, cholera and typhoid. The understanding about the correlation between wells, adjacent faecal sludge pits and clean water and health slowly developed during this time. Among experts grew the idea of simply flushing away sludge, waste and other debris from the streets with water. The development of the water closet is related to this conception. Thus wastewater was discharged into open ditches (often natural drains) and into the rivers, which even worsened the potential spread of diseases (Lange & Otterpohl, 1997).

B.1.1.1 Historical notes of interest - the debate about the choice of technology in the 19th century

In the 19th century many engineers and hygiene experts therefore favoured the idea to build sewers and keep the cities clean by flushing them with water. At least the hygienic problems within the cities would be mitigated through this measure. The introduction of the water closets and sewerage systems in combination with high investments in improved living space in England led to a measurable reduction of the mortality rate among the urban population (Virchow, 1868). However, for the problem of contamination of surface waters the engineers had no solution at that time.

For the supply of food, the urban population still relied on individual gardening and farming. Agricultural plots were common in residential areas and formed the appearance of parts of the cities. Faecal matter from collection pits was a major source of fertiliser and urban residents knew its value. It was either used to increase the yield of the gardening activities or was sold for money to farmers. The introduction of water closets and sewers destroyed this source of income and some citizens therefore rejected the new technologies (Lange & Otterpohl, 1997).

With regard to technology, several alternatives to the sewage system have been available at that time, for instance the “vacuum”-based *“Liernur System”*[6] and the *“Heidelberger Tonnensystem”*[7]. What is nowadays called “dry sanitation”, meaning sanitation without the need for flushing water, has not been considered as inferior at that time, but has been discussed as an equal potential technical solution for personal sanitation, and the technology has been easy and available. Interestingly these technologies already allowed a separate collection of the material flows greywater and blackwater / faecal matter and its reuse in agriculture. The advocates of these alternative technologies favoured them, because of the intentional reuse in agriculture. From the present perspective, this seems to be a very modern approach, but in fact it is not, as can be seen below.

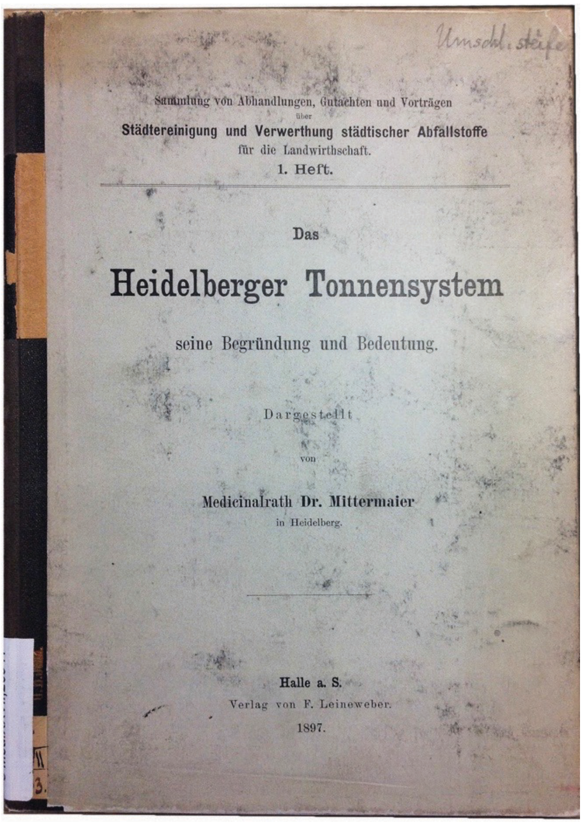
Historical records from the 2nd half of the 19th century show, that the discussions about the “right” system for urban hygiene and drainage have been very diverse. The disputations about the introduction of new technologies and its consequences have been strong and emotional, especially when it came to the reuse of faecal matter as an important fertiliser in agriculture. The book *“Sewers or removal?” (original: Schwemmcanäle oder Abfuhr?)* contains a subjective report from a congregation of German natural scientists, engineers, doctors, administrators and hygiene experts, and gives a good impression about how divided the experts opinions were at that time (Pieper, 1869). The topicality of this professional disputation with regard to current discussions related to NASS is remarkable.

Environmental aspects

The discussion about the sufficient **availability of arable soil** for the application of fertiliser from human excrements has been one major argument for the supporters of the removal system. While they had to admit that in towns without agricultural urban hinterland the sanitation question would be in the foreground, they also argued that in general it would be highly "*impractical ... to throw away millions of value in fertiliser and to make oneself costs in order to waste those millions*" (Pieper, 1869)[8].

It has been argued, that even the *"...impecunious class would be forced to contribute to the discard and therefore has to buy Peru Guano*[9] *and other artificial fertiliser for maintaining a small allotment garden or the like..."* (Pieper, 1869, p. 29 f.)[10]. A detailed consideration of the value of human excreta (urine and faeces) and comparison with Peru Guano based on the then actual prices and expected **income generation** in agriculture can be found in (Zehfuss, 1869, p. 6 ff.).

The question about the reuse of huge quantities of excrements in agriculture has been discussed in (Gruber & Brunner, 1871). In particular, **long-distant transport** due to high water content has been regarded as irrational and expensive as well as the obligation for a farmer to accept and apply “fertiliser” throughout the year seemed a disadvantage of the removal system. The need to develop a system which would allow for reduction of the water content and disinfection, while preserving the nutrient for the environment and allowing for longer transport distances and seasonal **application of fertiliser** from excrements is already described in (Gruber & Brunner, 1871, p. 42 ff.).



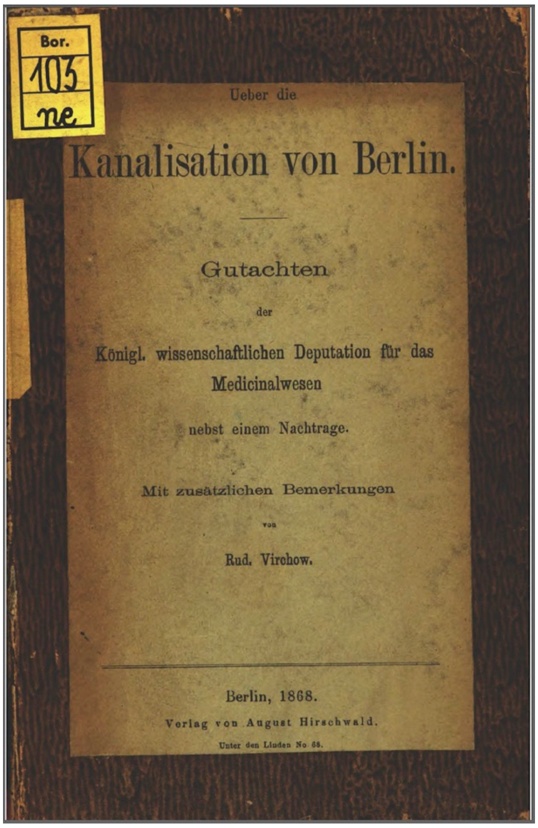


Figure 2: Insights in historical documents reveal modern discussions about the "right" approach to sanitation

Many experts were arguing passionately about the “poisoning of soil, air and water” and knew about interdependencies of human impact on the environment, resource protection and human health. They can be described as early *environmentalists* of the western hemisphere, e.g. in (Eigenbrodt, 1868).

Financial and institutional aspects

During the on-going discussion about the “right” system financial aspects played a significant role. For instance, in (Pieper, 1869) and (Gruber & Brunner, 1871) the question about related costs has been frequently discussed. Pieper says that the canalisation would cost a municipality “millions” while a removal system would only cost a fraction (“ten thousands”) of a sewage system. Furthermore, for a sewage system only the municipality would pay, while a **removal system** could be **organised by smaller private companies** who would pay an annual license fee to the municipality. Likewise he admitted that in big cities a central sewage system could be more recommendable under certain conditions (Pieper, 1869, p. 31 ff.).

Even more the idea of reducing the costs for municipalities by creating **benefits through** the value added **reuse of fertiliser** has been emphasised by Geheimrath von Salviati in (Pieper, 1869) as follows: *"Considering the municipal financial means, thus are the towns with removal just as well, as the canalised towns suffering from high costs, while with the removal a blooming horticulture and gardening culture goes hand in hand, whereby the edibles of the town become inexpensive"* (Pieper, 1869, p. 30)[11]. The loss of valuable fertiliser and potential **loss of food security** in combination with high **investment costs** for canalisation were one of the strongest arguments of the opponents of a centralised sewage system. Further on, once a city would come to the political decision to invest in a sewage system, it was considered as an irreversible decision because of the high investment costs involved. The determination on a single system, whose benefits were controversial at that time, would lead to **inflexibility and dependencies** of cities and their citizens **with long-term financial burdens**, according to the advocates of alternative technologies (Gruber & Brunner, 1871; Vogt, 1873, p. 8 f.).

Socio-economic aspects

Interestingly, the debate (in Europe as well as in North America) about the necessity to introduce sanitation systems has been often driven by assumed macro-economical benefits and much less by humanitarian aspects. It has been argued that the **loss of workforce caused by hygiene related diseases negatively impacts national economies**. In the early 1840s the English official and social reformer Sir Edwin Chadwick studied the disastrous living conditions of the British working class. His report sustainably influenced the discussion on social reforms and urban hygiene and emphasised the impact of urban hygiene and sanitation on economical loss and benefit of the British national economy (Chadwick, 1842, 1843). Other early estimations about the overall national costs showed that the investment costs into sewage systems would be a fraction compared to the economic loss caused by sick workers. Positive impacts of improved sanitation were measured in the **reduction of annual death rates** and associated with a theoretical **regained economic potential** (Keating, 1880; Virchow, 1868).

Despite hygienic aspects for the urban population, the questions of comfort, in particular odours have been argued widely. The possible threat for human health, in particular for sewer workers due to emission of foul gases caused by fouling of sullage in the canals, has already been described in (Virchow, 1868). As a solution, the sufficient flushing of the canals with water was implemented, which clearly showed the dependency of sewage systems on high quantities of flushing water.

Technical aspects

However, not only the above-described socio-economic and ecological differences of the competing approaches have been discussed in the 1860s and 1870s. **Technical deficiencies** also became apparent at the very early stages of development of sewage systems and have been widely debated. For instance, the problem of leakiness and hydraulic permeability of *“…sewer walls is everywhere admitted. … Groundwater infiltrated so widely through the brickwork that it formed a runnel at the canal bottom, whereas discharge of wastewater even did not yet happen.”* (Pieper, 1869, p. 26 f.)[12]. This statement has been made by the German Professor Virchow[13] in a report about a survey on newly built sewerage systems in Frankfurt, which were built under the supervision of the Europe-wide well-respected sewerage expert and chief engineer Mr Lindley[14]. Critical arguments can equally be found for non-pipeline bound systems, e.g. hygienic problems, strong odours and lack of convenience of use.

Various technical solutions were developed for the *collection and transport* of wastewater and excrements respectively. Looking at the historical documents it can be stated that the different technical systems for sewerage and bin or removal systems were equally detailed, designed and widely tested in practise. For example, for the *“Heidelberger bin system” (original: Heidelberger Tonnensystem)* a detailed technical description can be found in (Maquet, 1898). The detailed technical design was only one aspect, as often these documents served the author to express his personal views and to emphasize the **amenities** (e.g. comfort for users, level of maintenance, acceptance, odour, water use, amongst others) of the considered system that the author was representing, e.g. (Vogt, 1873) and (Mittermaier, 1897).

An interesting example can be seen in Figure 3, which shows a urine separation dry toilet (UDDT). Modern solutions from the 21st century still follow the basic design principles as can be seen in this picture from a “Swedish Air closet”. These type of indoor dry toilets were developed in 1855 and became popular in cities in Germany in the 1860s (Weyl, 1897, p. 93).

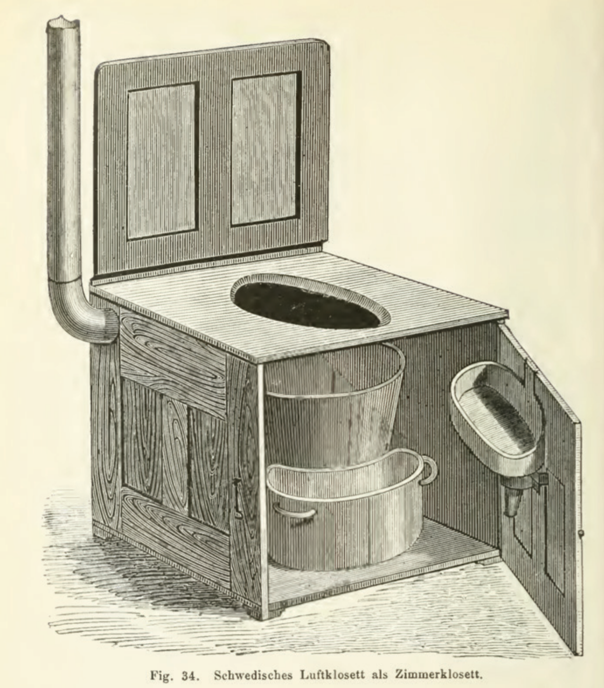


Figure 3: “Swedish Air closet” (Weyl, 1897, p. 94)

In contrast to the **collection** and **transport** solutions, the *treatment* of wastewater and excrements had a lower priority and far less technical options were available at that time. Mainly two options were practised: **Discharge** into the adjacent rivers and other receiving waters or utilisation of wastewater in agriculture. Sewage farms[15] or irrigation fields were a compromise for the supporters of the sewage system and the supporters of agricultural reuse as they allowed for a **pipeline-bound transport** in sewage lines without wasting the fertiliser value for the farmers.

However, the **numbers** of varying **different technical designs** and methods for collection, transport, (pre-)treatment and utilisation / disposal are remarkable, as is described in (Hösel, 1990), (Möllring, 2003, p. 89 ff.) and (Weyl, 1906). In fact, at the end of the 19th century, only 3.19% of 564 examined cities in Germany were equipped with a centralised sewage system. Even in major cities pit (majority), bin and bucket systems were predominant (Lindemann, 1901, p. 19 f.). Organic waste management has often been combined with or included within these approaches for sanitation.

The discussion on **utilisation** of human waste has been mainly influenced by the German chemist and “father of the fertiliser industry” Justus Liebig[16], who emphasised, that countries *“who waste their dung”* would fall into poverty over time (Dunbar, 1907). And indeed, nowadays it is no longer doubted that the rise and fall of most of the historic high cultures is directly and indirectly related to their relation with fertile soil, food production and the degree of realised sustainability in their agriculture (Montgomery, 2010).

Sewage farms became popular worldwide in the 2nd half of the 19th century and some of them persisted over more than 100 years. For instance, in the 1920s around 10,000 ha of sewage farms served as the main facilities for the treatment of wastewater of Berlin, which had almost 4 million citizens. At that time sewage farms were the most suitable facilities to prevent from the contamination of surface waters. Over time problems with soil contamination (salinity, heavy metals) and insufficient treatment performances due to overloading, high costs, lack of space and others, arose and the technology was abandoned eventually (Bjarsch, 1997; Reichelt, 2006).

Figure 4: Use of sewage farms “Gut Hobrechtsfelde” near Berlin (Senatsverwaltung für Stadtentwicklung und Umwelt Berlin, 2015)

Other developments, such as the originally profitable production of *poudrette* (an organic fertiliser made from faecal sludge, sweepings, and soil or peat) became uneconomical with an increased introduction of water-flush toilets, as this led to diluted excrements, combined with higher transport costs. Eventually the production (in Paris in 1884) stopped with **administrative decisions** to connect all sludge pits and water-flush toilets to the canalisation and the introduction of common fees for wastewater discharge (Möllring, 2003).

B.1.1.2 Outcome of decades of debate

In the end of the 19th century, the extension of water supply and canalisation systems accelerated in many urban areas throughout Europe. The water-bound sanitation systems offered increased comfort, convenience and good hygiene for a growing, economically wealthy middle-class.

In 1910, the invention of the Haber-Bosch process for the industrial production of ammonia and, contemporaneously, the increased production of mineral phosphate fertiliser from phosphate rock ended the need for reusing human excrements. The technological progress allowed to compensate the loss of human fertiliser in agriculture.

In the same period, end of the 19th and beginning of the 20th century, new scientific knowledge, such as modern urban hygiene concepts (Max von Pettenkoffer), chemistry (Justus v. Liebig), bacteriology (Robert Koch), and important technological inventions, such as comprehensive water supply, modern canalisation systems, the activated sludge process (W.T. Lockett) and others, eventually paved the way to modern wastewater treatment facilities.

Undoubtedly, the modern conventional sanitation and wastewater treatment system is a great story of success: Its significance for public health and its degree of reliance and acceptance made it become an indispensable infrastructure system for the modern society. It is considered to be intrinsically tied to an economically high living standard throughout the world and it is a major pillar of sustaining public health. Equally, there are certain downsides to this approach, as described in chapter A.

But it is to be emphasised, that **the discussion in this dissertation is not aiming to favour a certain technology or system.** Furthermore, it is intended to **reveal potentials** from historical approaches, compare them with shortcomings within the present developments **and develop ideas** for the future design of sanitation systems.

The question of the “right” system has to remain open

In the here reviewed historical discussions from the late 19th century and before, **the notion “*wastewater”*** hardly exists. Only in combination with canalisation has the notion been mentioned in (Mittermaier, 1870; Vogt, 1873) and later on defined in (Weyl, 1897, p. 10). The different views of the debating experts at the end of the 19th century approached the sanitation issue with the perception of different *streams* of *(polluted) water and / or debris* or *material flows*. With this different perception or mind-set, it seemed to be natural to consider different solutions throughout the ongoing discussion. In that sense, and although arguing passionately for their favoured system, earlier experts have generally been **open minded for different approaches**, even compared to experts nowadays.

The English Frankland scientific commission stated in 1870 that it would not be possible to follow schematic approaches towards wastewater disposal and wastewater treatment, but one has to decide one each individual case in an individual manner (Dunbar, 1907, p. 59). In (Mittermaier, 1897, p. 12 f.) and (Vogt, 1873) even the notion “*separate system*” is discussed, whereby it equally refers to dry and wet sanitation with a focus on the respective material-flows (including solid waste), instead of limiting it to domestic wastewater streams as it is understood in NASS today.

Dr. Adolf Vogt goes even further and argues in 1873 that “... *deep reforms in daily life rarely arise by instruction and persuasion, but almost always reach a state of implementation only by distress and delicate strokes of fate. Thus the current “sewer fever” must have left off steam and the subsequent infirmity of municipal finances and the disappointment of failed constructions needs to be enjoyed first in order to pave the way for rational reforms”* (Vogt, 1873, p. 2 ff.)[17]. Subsequently he offers a 5-step program to overcome the shortcomings of the so-called *sewer fever*, which would integrate conventional drainage systems with a removal and reuse system for excrements in agriculture.

This open approach can as well be seen as exemplary in reports of Professor Virchow who has been a supporter of water-based sewer systems but equally promoted dry sanitation systems depending on their feasibility and **adapted to the local framework** (Virchow, 1868, 1869).

What Vogt cynically describes as an *experiment* in 1873 already lasts for almost 150 years. But now his prediction of **lack of finances** becomes an issue for many municipalities, especially in rural areas and in developing countries with a lack of infrastructure and economic potential.

By analysing the experts’ argumentations in the late 19th century, several important observations have to be stated:

- Financial as well as technical aspects were not comparable at that time due to the lack of evidence based reference projects and experiences; this is obviously different nowadays.

- Mistakenly non-comparable urban and rural structures (e.g. differences in size, location, accessibility, degree of development and other) as well as technical solutions (e.g. sewerage with WC, separate system, under-pressure system, removal systems and other) were mixed up in the discussions.

In summary, an important statement can be derived from the historical discussions:
The diversity of human living environments needs sanitation systems, which are particularly developed for and adapted to the specific context. This also requires different technical and organisational solutions, which are not directly comparable, but have equitable eligibility depending on their context of application.

B.1.2 The prevailing paradigm of wastewater infrastructure decelerates innovation

Nowadays it is obvious to many researchers in the western developed countries, that a change of paradigm in the field of wastewater systems towards a circular economy is urgently needed, as is exemplarily described in (DWA, 2015). Likewise, many practitioners, mainly in developing countries, work increasingly towards sustainable infrastructure systems or NASS, as can be seen in the vast amount of pilot projects, case studies (more than 88 worldwide are listed in (SuSanA, 2016a)), and working material presented in the SuSanA network (www.susana.org) and others.

However, the global public paradigm in terms of what sanitation and wastewater systems should look like, draws a different picture: Regardless of having access to a conventional system or not, the WC - installed in each household - is the public standard, that needs to be achieved and by which other approaches have to compete with. In fact, when it comes to regulations and legislation, for instance in Germany, there is only one official working group of the leading engineering association DWA dealing with the subject NASS and so far only one guideline opens the door towards a change (DWA, 2014). All other standards and regulations are dealing with the conventional sewage system and are further developed from there.

A similar picture emerges when looking at internationally relevant and much respected standard literature, such as Metcalf and Eddy’s “Wastewater Engineering”. Figure 5 shows a schematic diagram of wastewater systems, which represents a pipeline bound sewage system in the 4th issue from 2004 (with treatment and disposal) and in the 5th issue from 2014 (Metcalf & Eddy Inc., 2003, p. 2, 2014, p. 4). This unchanged approach stands exemplary for the persisting one-sided paradigm of wastewater systems among planners, decision-makers, and the public.

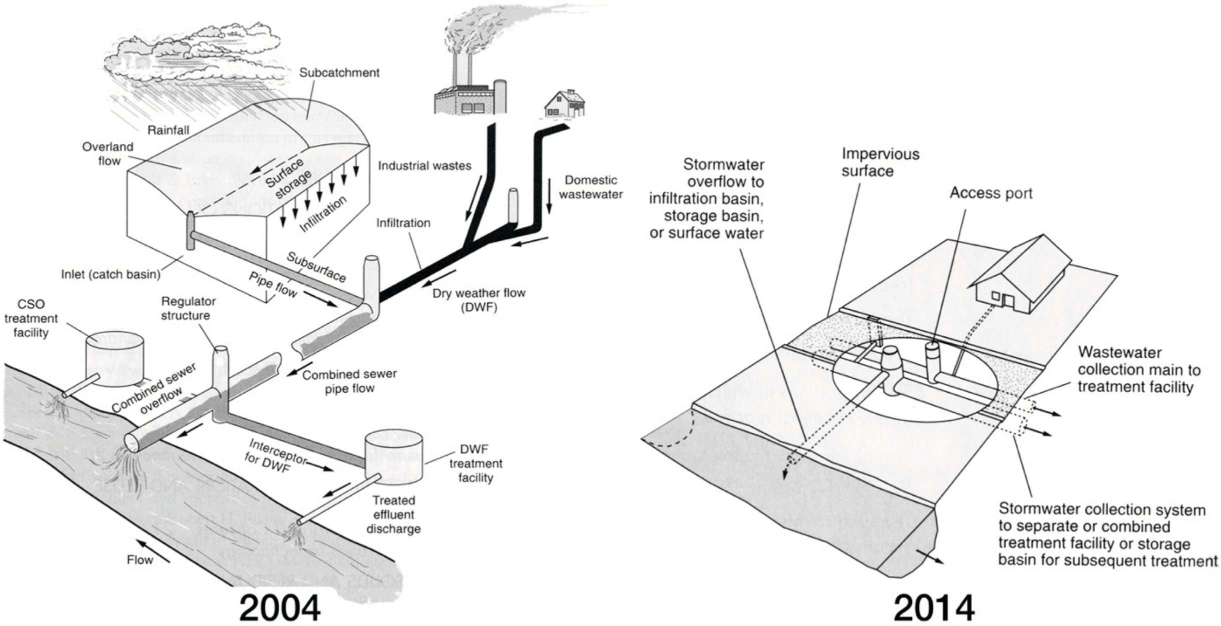


Figure 5: Schematic of wastewater systems (from Metcalf & Eddy, 2004 and 2014)

In western developed countries, the prevalent paradigm does not raise serious concerns, as drivers for change are low, particularly when comparing them to the reliable benefits offered by the existing infrastructure systems in place. One could say, “it just works, so why change?” The discussion is still led more on an academic level and the implementation is limited to pilot projects. Despite many well-regarded pilot projects all over Europe in the past two decades, the general self-concept of wastewater and sanitation systems remains stuck in the end-of-pipe philosophy, as can be seen in Figure 5.

Concerns of environmental sustainability, economic efficiency and resource limitation of the current systems are known, but are certainly not sufficient for a change. Additionally, the legal and institutional framework often anticipates the implementation of new ideas and the development of new technologies, which would be ready-for-market. The “freedom of choice” for abandoning the prevalent schools of thought and following a new paradigm is currently not given in western developed countries in the short term (Larsen, Udert, & Lienert, 2013).

However, the situation is totally different in economically more restricted or “underdeveloped” countries. A quote from (Lüthi, Panesar, et al., 2011) summarizes the results of this prevalent paradigm represented in technical guidelines and standards in a very comprehensive way:
“Existing laws, technical norms and professional standards are all part of legal frameworks which strongly influence investment decisions and sector innovation. In many countries, current legislation is overly restrictive, preventing re-use and blocking innovation. In the worst case,

unrealistic standards keep the urban poor un-served, stipulating flush toilets and sewers as the norm for all urbanised areas.” (Lüthi, Panesar, et al., 2011, p. 129).

In (Larsen et al., 2013, p. 135) it is estimated, that the establishment of efficient conventional wastewater infrastructure, as known in western developed countries, would take a timeframe of at least 50 years, given that there is an established engineering community and a stable organisational environment available. It is obvious, that these conditions are hardly to be found in developing countries and that prevailing conventional approaches can simply not offer a universal solution.

It is clearly known, that alternative approaches are urgently needed in developing countries

- to close the gap between the people with access to sanitation (often these are residents in urban centres with centralised sewage system) and those without
- to implement infrastructure systems which are realistic, that means adaptable, affordable, manageable and flexible in a rapidly changing environment.

However, it is not easy to change the prevailing paradigm of conventional wastewater systems as long as the knowledge of experts (state-of-science) is not reflected in the knowledge of the public and its representatives (state-of-the-art). Understandably the support of decision-makers and financial backers is only half-hearted, as is the preparedness of companies to invest into new technologies, as long as there is no market. **The prevailing paradigm of wastewater infrastructure decelerates innovation on a global scale.**

B.1.3 The need for new approaches for sanitation in countries with lacking infrastructure systems

As a result, efforts for developing new approaches, particularly in developing countries are driven by idealistic motivation and come in conflict with what is sustainably implementable and operable in reality. Pilot projects are funded for short periods of time, usually over three years, and not followed up. Technology is not available on the ground and re-invented over and over again as can be seen in the many case studies presented on the website of SuSanA or in (SuSanA, 2010).

B.1.3.1 Diversity of challenges and discussions about sanitation in the 19th and 21st century

In terms of the need for urban hygiene and sanitation, many residential areas in developing countries face realities, which are somehow comparable to the above described historical situation in central Europe at the end of the 19th century: The diversity of challenges nowadays seems to be as equal as certain arguments among experts. The following Table 1 summarizes hot topics and arguments of experts.

It is assumed, that the reader of this dissertation is somehow familiar with current discussions. Good overviews about the actual state-of-science are represented in (DWA, 2015; Larsen et al., 2013) and plenty of literature is available on websites, such as collected in chapter G below. It may therefore be allowed at this point to draw the attention to examples from historical sources, which can equally be found in the same manner in current discussions.

Table 1: Summary of the diversity of challenges for sanitation in the 21st century repeated through historical sources

Point of discussion / Deficits / Shortcomings	Discussed in 19th and 21st century (only historical sources)
Environmental aspects	
loss of valuable resources contained in faecal matter (fertiliser production)	(Zehfuss, 1869); (Gruber & Brunner, 1871); (Weyl, Gerson, & Vogel, 1896)
loss of arable soil	(Pieper, 1869); (Weyl et al., 1896)
contamination of soil, air, surface water and groundwater by lack of sanitation	(Maquet, 1898); (Eigenbrodt, 1868)
early environmentalists: concern about damage done to nature (interdependencies of humans and nature)	(Eigenbrodt, 1868); (Virchow, 1868)
high water use required for sewage system - no water for dry system	(Maquet, 1898)
Financial / institutional aspects	
economic deficiencies and high burden of municipal finances for sewage systems	(Vogt, 1873)
investment costs for bin system at a fraction of those for sewage system	(Pieper, 1869); (Vogt, 1873)
(regarding sewage system): irreversible decision because of the high investment costs	(Pieper, 1869)
forms of organisation: sewage system needs central structure of municipality; dry toilet system can be organised by private companies	(Mittermaier, 1897)
costs for high level of maintenance (dry sanitation and sewage system)	(Virchow, 1869)
costs for transport over long distance	(Gruber & Brunner, 1871); (Virchow, 1869)
fixed commitment to one system (high investment costs, political decisions)	(Vogt, 1873)
flexibility and adaptability of systems (independence) needed	(Maquet, 1898); (Virchow, 1869)

Point of discussion / Deficits / Shortcomings	**Discussed in 19th and 21st century** (only historical sources)
Socio-economic aspects	
introduction of sanitation driven by macro-economic interests	(Keating, 1880); (Chadwick, 1842)
loss of income generation by urban farmers – food security endangered	(Gruber & Brunner, 1871; Vogt, 1873); (Dunbar, 1907)
dependency on high quantities of flushing water in sewage system	(Maquet, 1898)
level of comfort for user and public acceptance	(Virchow, 1868); (Virchow, 1869); (Vogt, 1873)
contamination of drinking water wells due to leakages in the sewage system	(Gruber & Brunner, 1871, p. 27 f.); (Virchow, 1868)
bad public health and deaths due to lack of sanitation	(Chadwick, 1842); (Virchow, 1868); (Mittermaier, 1870)
Technical aspects	
determination on a single system, whose benefits are controversial, lead to inflexibility and dependencies	(Gruber & Brunner, 1871)
leakages of sewers lead to leaching of wastewater and contamination of soil and groundwater	(Mittermaier, 1870); (Pieper, 1869)
dependency of sewage system on high quantities of flushing water	(Maquet, 1898)
leakages of sewers lead to infiltration of groundwater into the sewer	(Pieper, 1869)
adapted flexible systems for urban centres are depending on their size, pace of development, resource utilisation	(Pieper, 1869; Virchow, 1868); (Lindemann, 1901)
high level of expertise and maintenance for centralised system needed	(Virchow, 1869); (Pieper, 1869)
demand for source separation to ensure value added reuse	(Weyl, 1897, p. 300 ff.); (Vogt, 1873); (Mittermaier, 1897); (Virchow, 1869)
impossibility to equip all cities with one singular system; different technical designs and solutions needed	(Virchow, 1869); (Weyl, 1906); (Lindemann, 1901)

The most interesting fact about this summary is the familiarity of the arguments from the 19th and 21st century. Despite the long history of development of 150 years and the big achievements in urban water management, it seems, that the fundamental problems either persisted over this long period of time or reappeared now in our present-day era.

B.1.3.2 Insufficiencies of the modern conventional WWT system with regard to transferability

The need for change in the way of thinking about infrastructure solutions is obvious in order to overcome the persisting problems in urban water management systems.

Certainly the basic principles of urban water management, as described in (Wilderer & Paris, 2001, p. 23) should remain untouched in any new approach:

1. Hygiene prevention and disease control
2. Resource protection through efficient water use
3. Protection of water bodies by detention of solid, faecal matter, and other oxygen-demanding emissions, as well as nutrients before discharge
4. Protection of soil and ground water by stopping contamination through wastewater

Main insufficiency 1: costs and affordability

The centralised, conventional WWT system is an important guarantee for public health and a high living standard in industrialised countries. But it comes with related estimated costs of almost 1€/cap*d, which is an amount that cannot be afforded by many people in developing countries. In reality this excludes the poorer and often bigger parts of a population from access to sanitation. By considering the aspect of the economy of the conventional system, it becomes clear, why the transferability to developing countries is not given.

In (Dockhorn, 2007) the annual costs for a global realisation of conventional WWT systems are estimated to be in the hundreds of billions of Euro, while at the same time destroying resources in a value of dozens of billions of Euro each year. In Europe increasing efforts are made to cover costs for the WWT by process optimisations, energy saving measures and reuse of biogas as well as income generation, for instance through recycling of sludge in agriculture.

However, the exploitation of economical potentials of the material and energy resources contained in the mixed and heterogeneous wastewater stream is very limited in the conventional system. Additionally, there are justifiable concerns about heavy metals, micro pollutants and endocrine substances, which restricts reuse options of the output of WWTPs. These are only some reasons why the change of paradigm in urban water management is continuing at an increasing pace, not only in Europe.

None of the mentioned problems are easy to address and can only be managed with a considerable effort of technology and very skilled human resources. Should these problems need to be considered in developing countries, they alone would in this case become disqualifying factors.

Main insufficiency 2: waste of resources

One other aspect, which comes back into focus, is the limitation of fossil phosphorus deposits. The current discussions among scientists do not show a clear picture. While precious estimations from (Cordell, Drangert, & White, 2009) predicted, that a peak phosphorus (similar to “peak oil”) would occur around the year 2033, more recent findings form (IFDC & Van Kauwenbergh, 2010) stated, that phosphate rock resources would last up to 400 years at current production levels. The data basis appears to be too insecure for more reliable statements. *“We know, we don’t know enough”* would summarize the need for further research on this topic.

Nevertheless, it is undoubted by all sources, that phosphorous remains a limited and irreplaceable nutrient for the nutrition of the world population. With a growing population and increasing stress on eroding arable soil, it is **already a limiting factor** for many farmers, particularly in developing countries. Up to a billion farmers, who are working on poor soils, need NPK-fertilizer but cannot access the markets because they cannot afford it. And as only 5 countries control almost 90% of the world phosphorus resources (Cordell, 2010), this is unlikely to change in the near future, should more equitable measures of distribution not be implemented in the world market.

Here is the **opportunity** for sanitation systems to mitigate the need of farmers for fertilizers by providing affordable and locally available fertilizers from wastewater treatment processes. In the case of food production, it would be theoretically possible to effectively recover the phosphorus used in human nutrition from human excreta (Larsen et al., 2013, p. 37,40). The problem is, that the conventional wastewater system - in the way it has been developed – is in itself an emergency system, designed to solve severe problems of public hygiene in densely populated areas. It is not a resource-based system (as it would be the case, e.g. in modern industrial production), which deals with material-flows and value-added outputs, but with a liquid form of waste.

Main insufficiency 3: water dependency

Fresh water for human use is still sufficiently available in Central Europe and the available resources are used without severe impacts on the available quantities, but fresh water resources are not evenly distributed. The EU water framework directive has led to WRM across nations with positive impact on water quality in many regions. Nevertheless the threat of long-term accumulation of micro pollutants, nutrients, and endocrine substances in our fresh water resources is not banned, but increasing due to agricultural production methods and discharge of treated wastewater (UNESCO, 2012).

The supply of drinking water is currently ensured in most of Europe, but about 1/5th or Europe’s population live in areas with increasing water stress because of over usage and climate change. The conventional WWT system is however depending on high water and energy consumption. According to (Siegl & Löffler, 2008) and (UBA, 2010), Germany’s WWT sector had the highest grade of centralisation and the highest wastewater fees in Europe. Extreme savings of water, triggered by environmental and economic awareness of the population, resulted in reduced wastewater quantities, which in turn led to increasing maintenance and costs for canalisation and the water supply system.

On a global scale, the problems are even more challenging when realising that most of the increased water usage is estimated for areas with an already high level of water scarcity. Even with efficiency improvements in water resource management and water provision, there will be a growing demand and increasing water usage in these regions (UNESCO, 2012). In combination with climate change it becomes obvious, why a Western-style conventional wastewater system is not a comprehensive solution in areas of water scarcity and can easily lead to more pollution of the fresh water resources available.

Main insufficiency 4: missing flexibility and adaptability

About one billion people still live in extreme poverty and cannot contribute to an expensive sanitation system. “Adapting” the economic conditions of these people to fit to the current systems would be prodigious, but will remain wishful thinking in the near future (United Nations, 2014). **Technology should be adapted to the needs of people and not vice-versa.**

Conventional systems require certain frame conditions for which they have been designed for and in which way they can operate as intended. As a high profile but static investment into infrastructure, such a system cannot easily be adapted to changing environments and demographic change (positive and negative growth).

Behaviour change of the population can challenge the regular operation of the system and may require additional measures, for instance as described above, surge flushing of canals with drinking water. Profound changes, which are exceeding the frame conditions of the system, would in the worst-case lead to a complete loss of the investment. A scenario, which would lead to such a loss of an investment, could for instance be caused by a combination of several factors such a declining population in rural areas, rapid urbanisation, increasing water scarcity and behaviour change. Realistic scenarios and possibilities for adaption in Central Europe have been widely examined in recent years, for instance in (Hillenbrand et al., 2010), (BUW, INAWA, & Tuttahs & Meyer GmbH, 2010) and the research project TWIST++ (Wolter et al., 2014).

In developing countries, the **acceptance and understanding** of the proposed infrastructure system by the future users of the system is crucial. The provision of infrastructure alone can only be of a very short-term and short-sighted political interest, but will - on its own - not lead of an improvement of living conditions of the affected population. Only if technical infrastructure is developed alongside the understanding and derived action of decision makers and users, it can eventually serve its intended purpose.

***Example*:** The following Figure 6 a.) and b.) shows the result of a complete loss of an infrastructure investment at a university building program in 2008 at Debre Markos University in Ethiopia.

Figure 6 a.) and b.): Disastrous living conditions due to loss of infrastructure investment at a university in Debre Markos, Ethiopia

The situation in this example has actually been caused by a number of technical and organisational failures from the client and the implementing agency. The Ethiopian government as the client has demanded a centralised wastewater system without thinking of any consequences with regards to education of residential students, provision of potable water, toilets and showers, or any other aspects of operation and maintenance. The technical execution of the building works was undertaken with a very bad quality and defective in several ways. The execution in this manner took place under the supervision of the international implementing agency, which was not ready to accept that a Western-style wastewater system would not work under the given conditions.

Some days of after commissioning of the new system, the water supply system and the wastewater installation in the buildings failed completely. As a result, the defective septic tanks were used as source of drinking water (due to groundwater infiltration). The students were using open wastewater streams for personal hygiene and partly had to practise open defecation, as the temporary pit latrines were not sufficient. Personal consultation with the students revealed, that many of them were suffering under these very unhealthy living conditions and with a variety of related diseases.

The system failure, caused by humans, resulted in a total loss of the investment from public money. Unfortunately, such an example is not an isolated case. However, it is valuable as a negative experience and **shows the importance of the need for adapted sanitation systems**.

B.1.3.3 Alternative approaches of ecosan, SuSan and others

The above-described problems have been long known by international experts who are working in this field. Alternative approaches, such as ecological sanitation (ecosan), resource-oriented sanitation (ROSA), sustainable sanitation (SuSan), decentralised sanitation and reuse (DESAR) and some more, offer potentials to overcome the persisting problems. All these different approaches follow similar principles with a different focus on certain aspects. Some of them have already been mentioned above in Chapter A.2 and Chapter B.1.2.

For instance, the definition of *ecosan* is described as follows in (Wikipedia, 2016): *“Ecological sanitation systems are systems which allow for the safe recycling of nutrients to crop production in such a way that the use of non-renewable resources is minimized. These systems have a strong potential to be sustainable sanitation systems if technical, institutional, social and economic aspects are managed appropriately.”*

All of the aspects, which are mentioned in the definition of *ecosan,* could also be found in the characterisation of SuSanA (SuSanA, 2016b), NASS (DWA, 2015) or others. It is not a goal at this point to examine the differentiations of the different alternative approaches, mainly as a lot the aspects will be discussed in more detail in the following chapters.

With regard to the idea of integrated systems, only some critical remarks can be made which certainly do not question the alternative approaches itself. The remarks are rather related to the implementation practices, which are described in the numerous examples of case studies and pilot projects (SuSanA, 2016a).

A worldwide survey done by the ecosan team of GTZ in 2010 estimated the number of users benefiting from an alternative sanitation system to be roughly 4.4 million people. Although the number cannot be verified, the survey gives an idea about the structure of the listed projects. Most of the international development projects focus on pilot projects, with a very limited number of beneficiaries from a couple of dozen to hundreds. Only bigger national programs, such as in China, Nepal, India and South Africa were actually able to reach a significant part of the (mainly rural) population from several hundred thousand to 2 million people. A similar survey examined the existence of recycling aspects in national policy strategies for sanitation in roughly 30 countries. However, no statements can be made about whether the projects were actually successful and whether they are still up and running sustainably. Equally the level of policy implementation of recycling aspects in sanitation cannot be verified (GTZ ecosan team, 2010a, 2010b).

As mentioned, the cited examples mainly focus on rural areas. It is much more challenging to implement these approaches in urban areas, where small-scale pilot projects are predominant. To tackle **problems of corruption, political lack of interest** and **lack of organisational knowledge and capacities** is hardly possible in an outcome-oriented project with limited resources and limited timeframe. Such alternative systems are often designed parallel to conventional approaches, and in areas where otherwise no official engagement is likely and where a project could hopefully be executed in a mainly undisturbed manner.

As a result, acceptance levels will be limited to the target population and have a low societal impact. Equally, technical solutions as well as institutional structures of alternative systems do not fit to existing conventional systems. On top of that the longer-term economic sustainability aspect is not elaborated sufficiently, as the technical and / or general project implementation remains in the foreground. So, despite the high potential of alternative approaches, there is still a long way to go towards sustainability and integration with existing infrastructure.

Additionally, with regard to alternative approaches and from personal experience, it has to be said, that there is a significant lack of reliable and efficient technology. Organisational questions remain an issue, but can never go without suitable technological solutions. This personal perception is also shared among well-established experts as stated in (Larsen et al., 2013, p. 136). In fact, projects fail frequently because of the lack of integration (in terms of user acceptance, systematic approach, economic sustainability) as well as missing reliable technology (small-scale and experimental, lack of money, self-made solutions).

Despite the critical remarks, it is undoubted that a lot of valuable work is done in this sector and very interesting methods and examples exist since many years. Most of this material is available online and freely accessible to everybody (see the Table of Literature for further information to online sources).

If and how much, the later on described approach of iSaS can contribute to tackle these issues, will at this point remain an open and critical question.

B.1.4 Non-adapted transfer of technology to different frame conditions in developing countries (climate, culture, socio-economy)

Experience has shown that in many urban development projects, the water supply, solid waste and sanitation infrastructure is insufficiently considered or even “forgotten” (personal experiences from projects in Ethiopia, India, Mongolia, and Cambodia).

The lack of sufficiently matured and adapted infrastructure solutions is a serious issue for the people and their environment. As a consequence, people live in precarious hygienic conditions and inhumane circumstances.

The common paradigm in people’s minds about conventional centralised infrastructure often prevents infrastructure projects instead of driving them: Conventional systems are too inflexible, expensive and costly to develop and install (see above). They can hardly react to dynamically changing environments in the urban context. For decision-makers, who are often not directly affected by the problems, wastewater infrastructure (in contrary to e.g. energy supply infrastructure) is just an inevitable evil, with which one cannot make money, but causes trouble and therefore is better postponed to future times, with better economical and easier political circumstances.

This point is well illustrated in a comment by Mr Jockin Arputham, the President of the National Slum Dwellers Federation of India where he states: *“No progress is possible until the urban authorities stop trying to hand down centrally planned solutions and start to throw appeals for help back at poor communities. … The urban elites are still clinging to the notion that they are the greatest experts in solving problems faced by the poor. It is an attitude which has led to literally thousands of failed projects.”* (WSSCC, 2004, p. 21). However, sanitation for the urban poor, remains “poor” if it does not equally have the potential to serve wealthier parts of a society, particularly as decision-makers are politically not interested to achieve a “*poor”* standard.

In (Keipp, Schuen, & Hoffmann, 2013) it is stated, that public funding is typically only allocated to sewer-based systems and that value chains are usually not considered. Neither the funding for essential investments is provided in the responsible societies, nor is the necessary administrative effort initiated, which needs to be undertaken to carry out the operative ownership of an infrastructure system and its maintenance. Often this is the unfortunate reality of conventional, as well as alternative approaches.

The necessity to combine such measures with accompanying awareness raising campaigns, educational work and vocational training is often not seen. These tasks are frequently not carried out by local authorities, which are often unable to cope due to various reasons. Examples of fundamental failure of authorities and project executing organisations can be found worldwide, e.g. completely new developed urban districts without any infrastructure systems at all or non-adapted systems, which break down after a short period of time.

One-side focused and deficient planning as well as omissions in the integration of implemented projects on different (societal) levels are often the cause for the failure of infrastructure systems. Also, alternative sanitation approaches are not free of such developments, as can be seen in the prestigious Erdos Eco-Town Project in China, in which the aim was to prove the feasibility of multi-story dry toilets in urban apartment houses (Jurga, 2009).

The fundamental problems with infrastructure systems are in its nature affected by cultural, financial, technical, structural, and education-specific causes or factors. These causes are interdependent and can only be addressed in its complex impact-dependency. If one is aware of the problem and the tendency of its future progression, only then an adapted solution can be developed (Londong, 2009).

Climate change, demographic change and changing availability of resources are decisive factors, which will lead to the diversification of the appearance of infrastructure systems (Winker, Stäudel, von Münch, & Londong, 2013).

For instance, Africa: The challenges faced by African cities with strong tendencies to urbanisation are huge: Increased resource consumption is in opposition to an increased lack of available drinking water resources and sanitation infrastructure. Despite a number of achievements in recent years, still only an estimated 83% of the population have access to clean water, whereas only 43% have access to sanitation infrastructure with steady tendency. Improvements in drinking water supply are questioned by the lack of sanitation. Due to the increasing pressure on available resources it becomes obvious, that conventional engineering solutions are insufficient to tackle the versatile problems (Jacobsen, Webster, & Vairavamoorthy, 2013).

B.1.5 Complement rather than decide – the need for integrated sanitation

It is undoubted, that infrastructure systems for growing and dynamically changing cities require different approaches towards sanitation. The discussion above actually shows, that there is no right and wrong in terms of sanitation systems. Both the conventional WWT system as well as new approaches are right and wrong at the same time, and a final answer can only be defined by failure or success, break down or functioning, rejection or acceptance.

Therefore, the question is not which kind of systematic approach (old or new, centralised or decentralised, conventional or alternative) one prefers, but how different approaches can actually work together and complement each other in order to benefit people and environment in the most efficient way.

This requires a conscious decision towards a more interconnected way of thinking of educators, planners and decision makers on many different levels. The development of integrated sanitation systems represents an idea for this conscious interconnected way of thinking and acting towards infrastructure solutions.

The root causes can mostly be classified in three main categories: **technology**, **economy** and **organisation**. Integrated infrastructure systems have therefor to be designed (technical, economical, organisational) in such a way, that all local circumstances are taken into account. This leads us to the next point “*integration*” in the following Chapter B.2.

B.2 Development of integrated sanitation systems

As has been shown above, the change of paradigm in urban water management is widely discussed in many different countries with varying framework conditions, but the implementation of *old* and *new* systems remains a challenge.

Resource-oriented systems based on separate collection, treatment and reuse of material flows are usually considered as a pre-condition for new sanitation systems. Combined with other systematic aspects like socio-cultural background, climate, ecology and economy, resource-oriented systems shall ensure the sustainability of new sanitation systems.

Although designed to be *sustainable*, many projects turn out to be not sustainable at all, usually after the end of the project period. There are many different reasons for the failure of so-called sustainable sanitation projects. An interdisciplinary and holistic approach in stakeholder involvement, adapted technology, legal and cultural implementation and economical operation of such a sanitation system offers the opportunity to let the change of paradigm in urban water management become reality.

The objective of this chapter is to develop a **concept for integrated sanitation systems**, which can be considered as sustainable under the conditions of the background of the local stakeholder. The necessary conditions shall be analysed and described for the further development of sanitation systems. The ability to implement in a large scale can be supported by this concept.

B.2.1 Disambiguation “*Integration*”

Before actually defining the notion ***integrated sanitation,*** it is worthwhile to examine where the notion *“integration”* actually derives from and get some clarity about its original meaning. After that, the current use of the notion *“integration”* in economic sciences and in relation to sanitation is assessed in order to get a better idea for the definition of iSaS.

Origin of the notion “integration”

The substantive “integration” comes from the Latin word ***“integratio”*** and is translated to “**renew, restore, complete,** and **incorporate into a bigger whole**”. The semantic notion comes with the idea of an actually existing intact whole.

According to the Duden the notion “integration” is defined as[18] (Duden, 2016):

- (educational language): “reestablishment of a unit, completion *and* inclusion, incorporation into a bigger whole”
- (sociology): “connection of a multeity of single persons or groups to a societal and cultural unit”

According to the Oxford Advanced Learners Dictionary the notion “integration” is defined as (Oxford Advanced Learner’s Dictionary, 2016):

- the act or process of combining two or more things so that they work together
- the act or process of mixing people who have previously been separated, usually because of colour, race, religion, etc.

to integrate: The verb “to integrate” comes from the Latin word ***“integrare”*** and is translated to ***“renew, complement, refresh the mind”***.

integrated: The adjective or adverb “integrated” according to (Oxford Advanced Learner’s Dictionary, 2016) is defined as ***“in which many different parts are closely connected and work successfully together”***.[19]

B.2.2 Integration in the context of economic sciences

Different levels of integration are used in economic sciences: ***horizontal, lateral and vertical integration***. Processes of differentiation and integration happen parallel and need to be balanced in an organisation. Differentiation here refers either to the breaking down of complex processes and structures into different specialised tasks or part processes and specialised departments respectively.

According to (Vahs, 2001, p. 46) integration is the contrary process of consolidation of single differentiated tasks. A goal-oriented differentiation and integration of processes is important to successfully manage market tasks as a whole. Management tasks are defined by a set of rules (communication). These rules define the interaction between different elements of the an organisation or company (Vahs, 2001).

Horizontal integration[20]

refers to the unification of similar companies or production processes under one common management. An example is the concentration (not necessarily the merging) of companies, who are active in the same market with the same product. Advantages are for instance common business strategies or more efficient resource management. Within one company horizontal integration is linked to an optimised flow of communication and materials on the same organisational level.

Lateral integration

is a variation of horizontal integration and mainly describes the unification of two companies or products, which do not directly compete with each other under one corporate management. The company follows a strategy of diversification in order to reduce market risks, whereas differentiated processes challenge the management skills.

Vertical integration

In economic sciences, the notion vertical integration refers to a form of inclusion of value-chains of production processes in one organisation. The goal is the optimisation of value chains and supply chains.

Basic tasks of organisational management

Differentiation and integration are basic (contrary) tasks of organisational management. The more complex an organisation becomes and the more diverse its activities or processes are, the more effort needs to be taken to integrate these processes again. In particular, the exchange of information and communication as well as interdependent tasks between departments, production lines and other has to be organised in a meticulous way. Differentiation and integration are therefore in some ways contradictory and need to be balanced and harmonised by a sufficiently worked out set or rules (Steinmann & Schreyögg, 2000, p. 402).

There is no rule on how to integrate processes in organisations as they depend on the actual situation. Identical part-processes can be unified in order to be more efficient, but should ideally not increase the organisational complexity (Vahs, 2001, p. 215).

Learning from economical sciences

Applying the economic theories of integration during the development of sanitation systems would lead to a very different approach of planning: Rather than starting with technical questions and trying to fit aspects of operation, finance, and administration together, a project planner would need to take on the mind-set of a business manager and perceive his sanitation project as an organisation or company or product, which needs to be organised in a most balanced way with coordinated (integrated) processes and technologies.

Neither engineers nor political decision-makers or administrators are usually very familiar with such an approach and this can easily lead to failures. Of course, not many stakeholders are likely to admit such a statement.

In terms of sanitation systems all the here-described aspects of integration can actually be defined: **Horizontal** integration is needed to coordinate communication flows, material flows and monetary flows, as well as the interdependent cooperation of different departments. **Lateral** integration is needed for the coordinated combination of different technologies. **Vertical** integration would help to define the way of value-added and management of resources and inclusion of different stakeholders on different hierarchical levels.

As all these processes are differentiated part-processes of the overall goal (or “company” or “product”) ***“functioning sanitation system”***, the commitment of stakeholders is required to consider these processes as part of a unified whole.

B.2.3 Integration in the context of water and sanitation

Environmental legislation in Europe and water resource management

In recent publications and European legislation, the notion “integrated” is often used in the context of comprehensive environmental management, for instance in environmental legislation, integrated water resources management (IWRM) or integrated urban water management (IUWM). With regard to river basins and water resources management the notion is well elaborated and established (GWP & INBO, 2009).

In other water-related areas or sanitation this is different. For instance: In (UBA, 2010, p. 87) the notion of *“integrated water management”* is only described as an extension of the concept of *“integrated environmental protection standards”* , which were described in European environmental impact assessment regulations from the 1990s. In Germany the notion of an integrated approach has been included in national legislation as well[21], but without being outlined in detail (e.g. in (BRD, 2009, para. 54 and 107)). Here it is just described as a new approach of *“…integrated prevention and reduction of environmental pollution…”* under inclusion of different environmental compartments and professional fields (BRD, 2009).

However, this new concept of extending a high level of protection of the environment as a whole (versus single subjects of protection before) is a significant novelty in the approach of European environmental legislation.

Water and sanitation

Similarly with regard to sanitation the notion is used in numerous publications such as (Makropoulos, Natsis, Liu, Mittas, & Butler, 2008) and (Benedetti, Dirckx, Bixio, Thoeye, & Vanrolleghem, 2008), but otherwise not further specified. In (Rost, Londong, Dietze, & Osor, 2014) the development of a new management approach for IUWM is described. Regarding the aspect of integration, it is stated in this publication, that there is still a lack of a systematic approach towards resource-oriented sanitation.

Further hints are given in (Herrle et al., 2005, p. 76) where a city-wide integration of organisational aspects for sanitation systems for the urban poor is demanded. An enhanced statement is made in the publication “*Integrated Urban Sanitation at Scale”* of the development bank KfW (Keipp et al., 2013), where it is emphasised, that *“… integrated sanitation concepts should be organised by a single operator or community”* and an integrated *“… sanitation chain begins on private property”* (Keipp et al., 2013, p. 9). However, no further aspects are elaborated and it is stated that the notion “integration” does neither refer to economic nor waste management aspects.

It becomes clear, that the notion integration is often used without clearly defining consequences for a planning process or project action, in this case related to sanitation systems. The word is used in a superficial way by assuming, that the reader has some kind of an idea about what it means. In practice this has hardly relevance and a specific application is not derived from labelling a system “integrated”.

The original meaning of the notion gives a clear guidance, of how to use “integration” in the applied context. The notions “renew”, “refresh the mind”, “incorporate” and “different parts closely connected and successfully working together” are essentially targeting the core idea of the change of paradigm in sanitation systems. These notions are certainly good drivers for the definition of iSaS in the following chapter.

B.3 Definition of “integrated sanitation systems (iSaS)”

Integrated sanitation is closely linked to IUWM and should be an inseparable part of it. Planning of concepts in a multidisciplinary manner is an essential part of IUWM (GWP & INBO, 2012; Leeuwen, Frijns, Wezel, & Ven, 2012; Mitchell, 2006). Integrated concepts for water management are focussing on different dimensions of integration, such as spatial, temporal or social dimensions (Vries, 2006), and a successful implementation should always be the main goal in the development of such concepts.

On the one hand, the challenges for the implementation of new concepts are bigger in developing and transitional countries compared to Europe: Often these countries have significant weaknesses with regard to essential financial, institutional and human resources (Horlemann & Dombrowsky, 2010). On the other hand, the possibilities and the degrees of freedom are much higher than in Europe. New ideas as well as new institutional and technical systems may be applied more easily in these countries without too many legal hindrances. But this is an advantage and a disadvantage at the same time, as a lack of legal framework is equally an indicator of the level of governmental development and official political interest. Similarly, there is an increased probability of corruption in unregulated areas of a society.

How can a concept for iSaS now be described in a most comprehensive way and serve as a “guideline” for implementation and operation? Can it actually give ideas for a practical applicable solution for urban infrastructure management? Can it provide a systematic approach or will it remain just a philosophical concept? These questions are the basis for the following discussion.

B.3.1 The idea behind “integrated sanitation”

The idea for the concept of integrated sanitation has been developed within the frame of the MoMo2 research project by a research team of the Bauhaus-Universität Weimar. Initially the concept was driven by the demand to find adapted solutions for wastewater infrastructure for the city of Darkhan in Mongolia.

For the case of Darkhan (see Chapter C) the main task was the development of a system, which would be able to combine existing infrastructure systems with well-known technology in the city centre with new technologies for the city fringes. Mongolia’s cities and in particular Darkhan undergo a period of rapid urbanisation. Due to different frame conditions a new solution needed to be developed, as conventional solutions were unsuitable.

Adaptable and affordable solutions would be needed and known mistakes from the past should be avoided. The idea of an overall holistic infrastructure system was approached in the following steps:

1. Analysis of local frame conditions (results from previous projects, data collection).
2. Examining conditions for and including of
    - technical (user interface (toilet), transport, treatment, reuse),
    - operational (legal framework and administrative structures),
    - and economic (business opportunities derive from financing model)

   system components, which are available and which should function as a unit.
3. Steps and goal of implementation: Capacity building + participatory planning = change of paradigm in urban water management through proof of concept.

During the research work, this approach has been further elaborated in more detail after a better understanding of the local circumstances in Mongolia, and even more by understanding the challenges for sanitation in developing countries as a whole. Similar projects in Asia and Africa have been studied.

According to (Stäudel, Khurelbaatar, Bruski, & Londong, 2012) the basic principles of an iSaS have therefore been described as follows:

- system is based on the material flows of the households: urine, faeces, organic waste, solid waste, greywater
- system includes collection, transport, treatment and re-use
- system is developed in a participatory planning process
- system can be combined with existing conventional wastewater treatment systems
- system shall be included into a regional sustainable infrastructure concept: economical resource management needed
- system offers the possibility to value-added reuse of the considered material flows in order to enhance the economical sustainability

Complementary for the implementation of a long-lasting functioning of waste and sanitation system some further preconditions should be fulfilled. These are:

- information and motivation of users,
- choice of inexpensive and adapted technologies,
- co-ordination with superior communal institutions,
- development of a clear organisational and financial structure (Pfammatter & Schertenleib, 1996)

An iSaS ideally offers value added by the most efficient treatment and reuse of all considered material flows and combines existing infrastructure with innovative sanitation concepts and technologies.

The idea of a holistic unified approach renews the paradigm of urban water management and enhances the field of activities beyond the common fields of engineering towards reuse possibilities in agriculture and adjacent industries as well as extended need for communication in administrative and economic structures. So far this is a very ideal imagination of approaching the issue of sanitation. It is certainly not realisable in a 1 to 1 implementation, but offers a reference point and guidance for new developments.

The general principles of iSaS are further on specified in the next Chapter B.3.2.

B.3.2 General principles of iSaS in detail

The general principles of iSaS are based on the definition of sustainable sanitation, which have been proposed by the Sustainable Sanitation Alliance. According to SuSanA (SuSanA, 2016b) sustainable sanitation involves the aspects as referred to in Figure 7.

Some planning guidelines for sustainable sanitation have initially been formulated in 2000 in the “Bellagio Principles for Sustainable Sanitation”, which involve human dignity, participatory planning, reutilisation and minimization of a practicable scale of implementation. Certainly, iSaS should equally value these principles. It is obvious, that the idea of iSaS is nothing entirely new. However, there are some differences in the approach, the main target area, and the necessary framework conditions for iSaS.

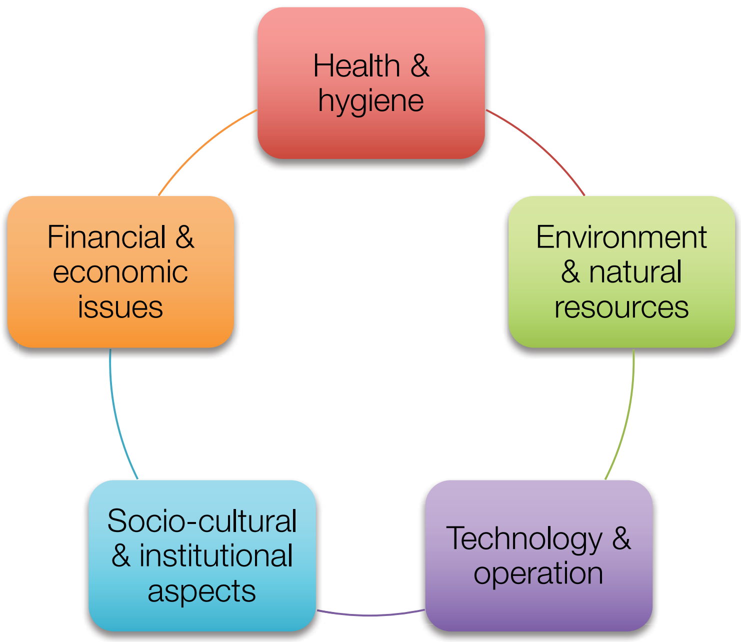


Figure 7: Aspects of sustainable sanitation formulated in (SuSanA, 2016b)

The development of the concept of SuSan is mainly based on the experiences from lack of sanitation in developing countries and is specifically tackling these problems. In particular, in areas where a local government is not able to cope with the sanitation problem at all, SuSan can offer an alternative approach. If official structures for infrastructure development are hardly existing and experts’ knowledge and education levels are low, SuSan offers not only tools to support the self-organisation of communities, but equally provides guidelines on different levels for planners and decision makers.

The idea of iSaS though, needs to be differentiated from SuSan by looking into its main aspects and framework conditions more in detail.

Main differentiations of integrated sanitation and framework conditions

The concept of iSaS emphasises some aspects and focuses on target areas with specific suitable framework conditions:

1. iSaS is **not** offering an alternative or parallel approach to a conventional or any other system, but aims at the inclusion of different solutions.
2. iSaS demands the integration of existing infrastructure into an overall infrastructure concept or master plan for infrastructure development.
3. iSaS focuses on urban and peri-urban areas with possibilities to use or create institutional structures, which can handle the operation of the system.

The reason to emphasize on these 3 points is driven by the idea of a push for the change of paradigm in urban water infrastructure. Certainly, this change is neither immediately implementable everywhere, nor would it always be feasible.

A number of aspects have to be considered in order to justify the need for an elaborated master plan for infrastructure. These aspects are technology, ecology, settlement structure, economy, socio-culture and institutions. The following table summarizes important criteria and indicators related to the mentioned aspects.

Table 2: Criteria and indicators as framework conditions of iSaS

aspect	criteria	indicator	requirement and / or objective for iSaS
technology	- technical standards - service level: water, waste, energy - state of existing infrastructure - reuse options	- level of technological development - applicability and sufficiency of technical standards - connection rate - service reliability / operation - maintenance level - operational reliability - remaining value - value of fertiliser - fertiliser market accessibility	- iSaS has to fit to the general state of development - need to be applied or improved - develop towards 100% - to be evaluated & optimised - to be evaluated & optimised - to be evaluated - to be evaluated as reuse depends on market accessibility
ecology	- climatic conditions - natural resources - topography	- temperature, - water availability, hydrology - soil - construction material - elevation, slope	- basic data for system design - to be adapted to - influence on reuse possibility - natural resource for system, influences design - influences system design
settlement structure	- number of users - accessibility (transport ways) - legal status	- population density - spatial development / density - existing infrastructure - formality of settlement	- needs to be sufficient - needs to be suitable for technological design options - must be considered and included - formal settlement needed
economy	- economic system - economic resilience - affordability - economic benefits - finance	- free or restricted market - entrepreneurship ←→ state ownership - employment status - economic growth - willingness-to-pay / wealth / sufficient income level - costs for communal services water, waste etc. - income generation - creation of jobs - financial capacity of operator / institution / municipality - business plan - liquidity / credits	- must be considered - must be considered - must be considered - should be stable - needs to be at minimum level, not suitable if population too poor - to be evaluated and optimised - ideally improved with iSaS - ideally improved with iSaS - needs to be considered / build up capacity - build up capacity of long-term operation - build up capacity for long-term operation

aspect	criteria	indicator	requirement and / or objective for iSaS
socio-culture	- religion - culture - education - gender - physical and mental capacity of population - societal stability	- special rules - faecophilic ⟷ faecophob / washer ⟷ wiper / squatter ⟷ sitter - literacy / educational level - traditional male and female roles - public health status - security - peace	- must be considered - must be considered - must be considered - must be considered - good to be known, should be improved - minimum stability required - peace is pre-condition
institutions	- state structure - legal framework - legal system - institutional capacity	- political situation - government - national, regional, local legislation - environmental law - legal certainty - functioning jurisdiction - level of corruption - expertise and intellectual capacity - reliable administration and management capacity - level of centralisation / capacity of local decision-making	- needs to be stable - needs to be included - needs to be considered / respected / improved - needs to be considered / respected / improved - important for economic operation - high level of corruption is main disqualifying indicator - needs to be considered - minimum level required - local decision-making capacity necessary

The table above shows, that iSaS is not a concept that can be implemented immediately all over the world. It requires a certain stage of development and stability of a society, as well as a minimum capacity to deal with complex technological, economical and institutional tasks. It is therefore hardly suitable in emergency situations, war zones, or unstable states and societies. Equally it may not be very suitable for the poorest communities, as a minimum level of wealth is necessary for people in order to be able to deal with issues, that are not directly related to daily survival.

Relevance of iSaS with regard to people without access to sanitation

However, from the 2.5 billion people without access to sanitation on the planet, a significant number can potentially be reached with this concept. This has been shown in a simple study at the Bauhaus-Universität Weimar:

The iSaS, which was tailored to the local conditions and the situation in Mongolia, has been used as a reference. The proposed technological solution from the MoMo2 research project (further described in the Chapter C) has been examined with regard to its potential global transferability to similar circumstances in different countries and climate zones. The number of people, who are living in surroundings (refer to Table 2), which would be sufficient for the application of the iSaS concept, has then been estimated.

The estimation showed a huge worldwide potential: from the above mentioned one third of the world population, around **575 million people in urban and peri-urban environments could be served** with such an integrated sanitation system (Feldmann, 2013). As only the people without access to sanitation have been estimated, and only a certain technological solution has been considered in this estimate, the number of people who could be included in an iSaS would be considerably higher.

Guideline for the design of iSaS

The main demand of iSaS is literally the *integration* of different conscious and unconscious levels of an infrastructure project. The aim is to consciously combine these different levels into a *functioning whole, where many different parts are closely connected and work successfully together*, which means basically adapting and integrating technologies, operation and maintenance, with community participation and capacity development (CD) in one method.

In order to streamline the approach and shape it in a comprehensive way, some guidelines are derived from the principles of iSaS. These guidelines are expressed in the three levels of iSaS in the following chapters.

B.3.3 The three levels of iSaS

In order to be able to consider the manifold aspects in its entirety, it is useful to structure them in three descriptive “levels”

- material-flow, energy-flow and technology
- monetary-flow and economy
- communication-flow, stakeholders and structures.

In the following Table 3 the three “levels” of iSaS are summarized.

Table 3: Three levels of iSaS

Level material-flows / energy-flows / technology	Level monetary-flows / economy	Level communication-flows / capacity development / structures
material-flows	investment costs	initial participatory measures / stakeholder analysis
energy-flows	operational costs and maintenance	participation, education and training
user interface / collection	unit costs / annual costs	institutional capacity development
transport system	income generation	public education and public relations
storage / treatment process		
product output / reuse strategy		

These levels are in its structure based on to the three-pillar-model of sustainability[22] (environment, society, economy), which is widely used in different professional fields. The three-pillar-model is often used in different approaches for the assessment of sustainability, as has been described in (Fach, 2013; Meinzinger, 2010; Nayono, 2014; Remy, 2010). With regard to urban water infrastructure systems it has been further elaborated in (Hiessl, Walz, & Toussaint, 2001) and others, where also criteria have been defined for the respective sustainability assessment.

However, it is not intended to examine the degree of sustainability in this work. It would certainly be worthwhile to examine the degree of integration of an infrastructure project and combine this with statements of sustainability and future prospects. Therefore, reference is made at this point to the cited literature above.

The notion *level* is used to express the interdependency of the various aspects. These levels should not be considered as independent and side-by-side, but rather as built-upon each other. They always need to be adapted to the specific context and have therefore no claim to completeness.

Further on in this work, the levels are also used as basic idea for the “*layers*” in the mathematical model for iSaS. They serve as the theoretical foundation for the comprehensive presentation of the mathematical iSaS model (see Chapter D).

One statement is to be considered:
Sanitation systems based on material-flows ***can*** *have a much higher technical and organisational level of diversification compared to conventional systems. The more diverse a sanitation system is, the more integration is needed.*
The basic principle is*:* ***higher level of diversion → deeper level of integration***

B.3.4 Level material-flows, energy-flows, and technology

iSaS are resource-based systems. They are comprised of material-flows urine, faeces, greywater, rainwater, and can equally include other biodegradable material and residues from agriculture, domestic waste and industries. This idea is nowadays state-of the-art and therefore not repeated here. The notes are kept short and reference is made at this point to the relevant literature such as (DWA, 2014, 2015; Larsen et al., 2013). Further on energy-flows are included in the system, which are mostly parallel to the material-flows.

Description of main material-flows

The material-flows differ strongly in their chemical-physical and biological qualities as well as their quantity. By not mixing the different material flows, it is possible to apply efficient treatment processes for each material-flow in the most adapted way.

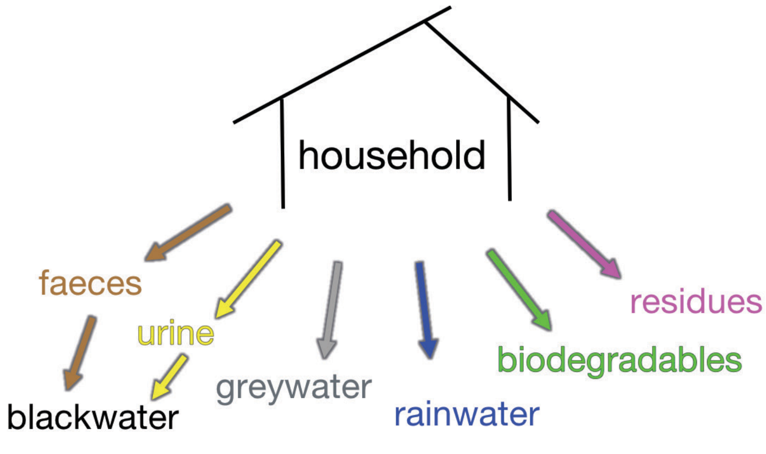


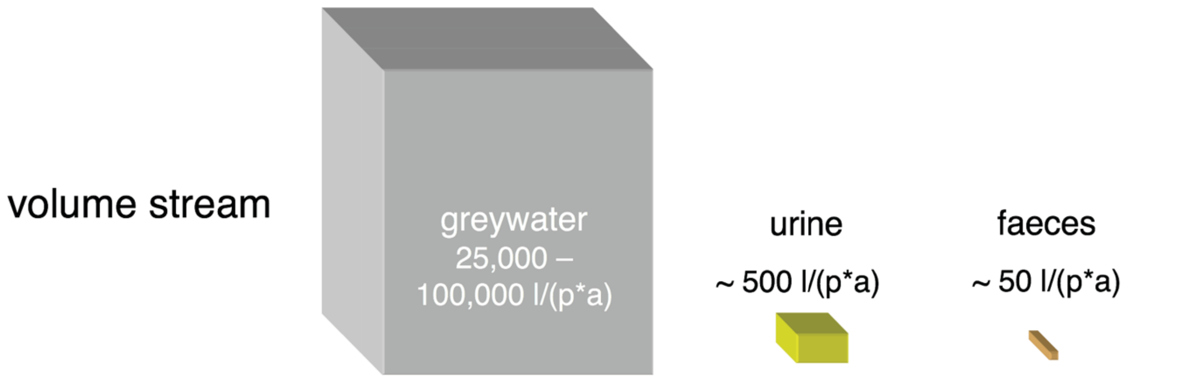
Figure 8: Material-flows at household level based on (Wilderer & Paris, 2001, p. 16)

Previously, with mixed material-flows, a contaminated wastewater was produced, which could only be transported with a pipeline-bound system and required treatment and/or had to be disposed of. This resulted in centralised and very inflexible structures and is called the conventional wastewater system. With separately kept material-flows, it is possible to create a huge variety of technological solutions through numerous possibilities of combination of different technologies.

These can be specifically adapted to local circumstances and do not need to follow a centralistic approach. Further on it is easier to apply technologies, which are reliable only within a specified time frame, and which are presumably more cost-effective. As investment costs can potentially be kept low, there is no obligation to run a system over a very long time period until it is refinanced. This means, that a resource-based system possesses timely and spatial flexibility.

The following Figure 9 shows the volume streams of the primary material-flows of resource-based sanitation systems. The diagram also displays the average annual loads of N, P, K, and COD per capita with regard to the material-flows.

The constituents of these primary material-flows are further described in Chapter D.2.5 with regard to the mathematical model.



			greywater	urine	faeces
N	~ 4-5	kg/(p*a)	~ 8 %	~ 81 %	~ 12 %
P	~ 0.75	kg/(p*a)	~ 25 %	~ 50 %	~ 25 %
K	~ 1.5	kg/(p*a)	~ 24 %	~ 60 %	~ 17 %
COD	~ 43	kg/(p*a)	~ 40 %	~ 9 %	~ 51 %

Values updated according to median in (DWA, 2015. *Neuartige Sanitärsysteme.* pp. 12-15)

Figure 9: Characteristic annual values of main material-flows of resource-based sanitation systems (updated according to J. Niederste-Hollenberg)

Besides more efficient and flexible treatment options of a resource-based system, the other main goal is the possibility to achieve value-added through the output of saleable products. The combination of conventional (probably existing) technologies with alternative technologies in an overall system is nevertheless possible. Technical reliability within a certain time frame and adaption to climatic and socio-cultural conditions can be more easily obtained in a resource-based sanitation system.

Energy-flows in the system

Energy is used throughout the whole infrastructure system in all activities. Mostly energy is needed for the handling of the material-flows, such as transport, storage, and treatment. At some points within the system energy can also be regained, for instance in a biogas plant (e.g. heat and electric energy).

Energy-flows are mostly parallel to the material-flows within the boundaries of the considered system. Therefore, energy-flows are disclosed wherever energy production and energy consumption is known (refer to Chapter D.2.6.).

In order to be able to integrate energy-flows, estimations on the use of energy sources for operation (e.g. fuel, electricity, heating) are included by considering energy use in form and quantity (e.g. kWh, kWh/km, kWh/m^3). This is a simple way to deal with energy-flows in the system without exceeding the system boundaries and keeping the complexity at a manageable level.

System boundaries of material-flow and energy-flow analysis in iSaS

The consideration of material-flows and the energy-flows in the iSaS approach focusses on the practical implementation. It does **not** examine the environmental impact of a sanitation system over its entire lifespan including aspects of energy and material use for resource extraction, manufacturing, transportation, construction, period of use, demolition, recycling / disposal as is usually done in life cycle analysis (LCA).

Technology available for iSaS

A numerous variety of technological options are readily available or under development as can be found in (GIZ, Rieck, von Münch, & Hoffmann, 2012; Niwagaba, 2009; Reckerzügel, Gutterer, Sasse, & Panzerbieter, 2009; Sasse, 1998; Strande, Ronteltap, & Brdjanovic, 2014; Tilley, Ulrich, Lüthi, Reymond, & Zurbrügg, 2014) and many others.

For a planner of a resource-based system, choosing the most appropriate technology can become a challenge and some downsides have to be mentioned here: There is still a **lack of reliable and proven technology** from toilet, to transport, storage and treatment, that is **specifically designed to fit together**.

This has also been stated in research work done at the Bauhaus-Universität Weimar within the frame of the MoMo2 research project. Compared to conventional systems the available technical options did not have the time to mature. Therefore, substantial development work is still needed to achieve the same high level of reliability, acceptance, and marketability of alternative source separation technologies for **user interface** (toilet), **collection** (e.g. container, pits), **transport, storage, and treatment** in particular, as all these aspects of the system **have to work seamlessly together**.

Example for new developments: Some recent designs for a diversion toilet point into the right direction, for instance the development of the blue diversion toilet by the EAWAG research group (Lüthi & Larsen, 2014).

Figure 10: Development steps of blue diversion toilet (taken from www.bluediversiontoilet.com, accessed 2016-04-10)

The development steps of the blue diversion toilet (see Figure 10) are a good example for the necessary effort that needs to be undertaken to bring a product to marketability.

This example, as well as many other locally developed and successful pilot technologies, can serve as important drivers and motivation to put even more effort into the development of alternative technologies. Reliable and accepted technologies eventually prepare the way for the implementation of resource-based systems such as iSaS in the future.

B.3.5 Level monetary-flows and economy

The level monetary-flows considers investment costs, operational costs and maintenance, unit costs / annual costs, and potential income generation through reuse of products from the treatment process. The adaptation of the whole system to the local socio-economic situation is crucial. Without a reasonable design of the economical level of the system it is not possible to achieve acceptance within the target population. The value of technical equipment has to be adapted to the local economic status, equally as investments and operational costs, without cutting corners on reliability.

Money as important criteria in the decision-making process

The use of money and costs as decision criteria is subject to strong fluctuations and delivers a snap-reading method based on available (often incomplete) data and / or assumptions, which can be interest-based and politically influenced. Particularly in developing countries, long-term economical sustainability may come second to declared governmental approaches or personal interests of decision-makers. However, costs are an important parameter in efficiency assessment and decision-making processes.

Different models for the evaluation of costs are available, whereas the cost comparison calculation is well established for conventional wastewater systems. The cost comparison calculation requires benefit equality of the regarded alternatives and only includes monetary aspects, whereas cost-benefit analysis and cost-effectiveness analysis also consider non-monetary aspects. The difficulty is the conversion of non-monetary aspects or benefit values into measurable, monetary units (Hein, Lévai, & Wencki, 2015, p. 202).

The main mistakes in evaluation processes often come from neglecting varying benefits and risks of the compared systems. That means, in practise decisions are often made on the basis of cost comparison calculations in order to determine the most economical alternative of an investment. However, in case the proposed alternatives have varying benefits, a **decision based on cost comparison alone is not permitted** and would most likely lead to a wrong choice.

Monetary-flow and flow direction

In the development of an integrated infrastructure system this is significant, as by its nature, iSaS are distinguished by diverse technological and organisational characteristics. Project management agencies and planners would therefore be obliged to further examine (non-monetary) benefits and risks with suitable scientific methods such as use-value analysis, life cycle assessment or other one or more-dimensional evaluation methods as shown in (Fach, 2013, p. 59ff) and (Hein et al., 2015, p. 202 ff.).

Costs in conventional approaches usually “flow” in the same direction as the material-flows “away” from the user (actor 1) towards the operator or owner (actor 1+x) of the infrastructure system, which is usually the municipality or a private company or a combination of both. The notion “*flow*” in this case means the act of handing over of money from one actor within systems to the next, in order to recover the costs of the service that has been used. The next Figure 11 shows the flow of money in a conventional wastewater treatment system in a simplified way.

Figure 11: Direction of monetary-flow in a conventional system

In iSaS monetary-flows are not only determined by costs and cost recovery measures related to the public infrastructure system. By extending the planning activities on the aspect of resources utilisation of the content of the regarded material-flows (N, P, K, water, energy) it is assumed, that monetary-flows can partly be reversed and contribute to a higher self-sustaining system. By this means, iSaS have the potential to become the more affordable choice of infrastructure and can thereby contribute to poverty reduction. The following Figure 12 shows the flow of money in an iSaS in a simplified way, where some costs can be covered by saleable output products from the system.

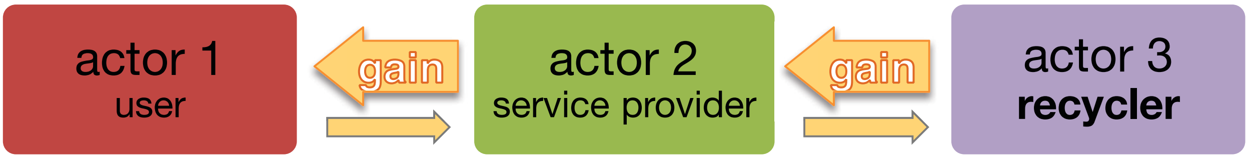


Figure 12: Reverse of direction of monetary-flow in an integrated system

Material-flow and energy-flow mostly parallel to monetary-flow

Energy is needed for the handling of the material-flows, such as transport, storage, and treatment. At some points within the system material and energy can be regained, for instance at a biogas plant in the form of nutrient-rich slurry, methane, heat, or electricity. Material-flows, energy-flows and monetary-flows are mostly parallel within the system, but their direction is not necessarily rectified. Whenever material or energy “flows”, there are costs or income involved.

Material and energy-flows have a positive or negative economic value within the system. Beside obvious costs such as investment, repayment, or salary, the economic value of nutrients contained in the material-flows as well as produced energy is included at current market prices, and wherever consumption or production is known within the system (refer to Chapter D.2).

The importance of operation and maintenance

Particularly in developing countries, the issue of operation and maintenance is the most critical factor of infrastructure. Sometimes a private operator or service provider can be a good choice. But it is not possible to give general statements on this issue, as it is too dependent on the circumstances. Often, local politicians are members on the boards of private operators and are heads of municipalities in a control function, which they cannot fulfil due lack of expertise.

Independent experts – if existing - often lack the executive power to control the quality of the performance of a service provider. For this reason, private or municipal operators are often spared by sophisticated controls. A high level of corruption can then easily prohibit the implementation of an infrastructure system.

Maintenance is an important factor to ensure the continuous and damage-free operation of the system. Usually it is cost and personnel intensive. Not executing measures of maintenance is a way of postponing costs into the future. Costs for maintenance and operation must therefore be considered in the development of iSaS.

The above described difficulties are to be expected in all countries and can only be addressed by a well-elaborated economical design of a system and most transparent cooperation with stakeholders and decision-makers. In particular, **iSaS have a potential to mitigate the negative impact of corruption by creating public awareness and transparency**. This leads to the next level of iSaS: communication, capacity development, and structures.

B.3.6 Level communication-flows, capacity development, and structures

The reason for a missing sanitation infrastructure can often be found in insufficient awareness and lack of interest of political decision-makers. Conversely, the responsibilities for sanitation measures often lie on a low (local) level of the administration. Even after decentralisation measures the local administration is often left alone with this problem and the budget for sanitation is not equally decentralised and allocated to the local level. Further on there is hardly qualified staff to be found, which would have the capacity to deal with the existing challenges (BMZ, 2008). Capacity development and multiplication of expertise and sharing of experience is the most important *“soft”* factor of iSaS in developing countries.

The case of Darkhan, Mongolia in the following Chapter C is actually an example, which describes such a situation very well. Several measures, which help to overcome these deficiencies are explained below as part of the iSaS level communication-flows, capacity development, and structures.

Main elements of the level communication-flows of iSaS – guiding principle tasks

Plenty of methods are available for raising awareness and building capacities in the sanitation sectors, whereas the participation of relevant groups of the population is always described as an initial starting point. The needs and requests of residents have to be heard and stakeholders need to be identified and involved.

Traditionally infrastructure planning is done in a top down approach, where officials (together with their experts) at national level down to municipal level decide about regulations and infrastructure projects, without sufficiently considering the needs and framework conditions of the population (EAWAG, 2005). Particularly in developing countries this leads often to non-adapted, poorly planned or failing sanitation projects.

The bottom up approach in sanitation tries to balance the need of the users with the provision of legal framework and services by official organisations, but usually lacks the efficiency and political power in order to achieve significant impact. Integrated infrastructure planning and **iSaS has to serve as a mediator** between these opposing approaches, as can be seen in Figure 13. Some guiding principles for iSaS can be derived from this idea, which are based on practical experiences and are equally described in many methods of participatory planning.

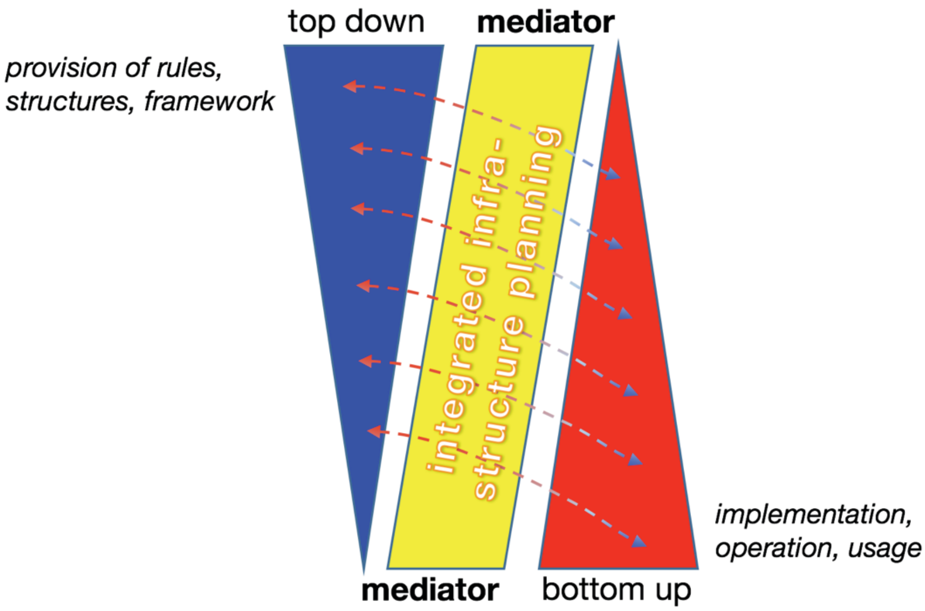


Figure 13: iSaS as mediator between top down and bottom up approach

The following aspects can be named as **guiding principle tasks of iSaS for communication**:

1. analysis of stakeholders
2. definition of enabling environment
3. development in an interdisciplinary and iterative process
4. involvement of citizens and inclusion of relevant stakeholders in order
    - to raise awareness
    - to minimise misconduct of users
    - to create acceptance and a sense of ownership
5. inclusion of further experts from agriculture, social works, urban planning, economy, administration (where applicable)
6. inclusion of the paradigm of resource efficiency and added value as basic orientation
7. adaption of operation and maintenance to the specific context, which may include
    - education and training of staff
    - institutional capacity development
    - public education and public relations
8. adaption of finance model to the specific context
9. implementation, construction, operation with local resources (if possible)

Stakeholder analysis build upon material-flow-analysis

As an initial step the stakeholder analysis provides an important entry point into integrated infrastructure planning. It helps to identify the key organisations and persons, which need to be addressed in the participatory planning process.

The relations among each other need to be analysed as well as their particular interests, their influence in the planning process and ability to support implementation and sustain operation. A tool that is commonly used in stakeholder analysis is the stakeholder map or stakeholder matrix, which is shown in Figure 14. The stakeholder matrix is a visual tool used to assess the power of influencing the planning process and the motivation of stakeholders to get actively involved respectively. In the beginning of the process it can only display a first impression of the stakeholders. The matrix should be verified from time to time, when familiarity with the partners and the understanding of their roles increases during project progress. In Chapter C the use of the stakeholder matrix is exemplarily described at the practical example of the city of Darkhan, Mongolia.

In a second step, the mathematical model can be used to better describe the role of a respected stakeholder within the system and its interaction with other stakeholders. The model is created by using the example of Darkhan and is described in Chapter D. It is based on the method of a material-flow-analysis (MFA) and provides a visual representation of the material-flows in iSaS.

The guidance of the material-flows requires a set of actively set rules and policies. The impact of legislation can be visualized and the need for adaptation of legislation can be explained in a more coherent way to all relevant stakeholders. Infrastructure systems, which are based on MFA, are likely to be more cost effective. The impact of decisions and measures is more transparent and responsibilities are better understood (Brunner & Rechberger, 2004, p. 305f.).

Only if a diligently undertaken stakeholder analysis is done, the MFA can provide the basis for societal and political decision-making in sanitation and environmental systems. It is therefore important to harmonise higher-level interests of political decision-makers with societal needs based on the results of the MFA.

On the basis of the MFA, relations within a social structure can be visualised, and also the interests and potential conflicts among stakeholders can be analysed before the background of the quantitative assessments. This will support the development of strategies for communication, balancing of interests and further the implementation of the system.

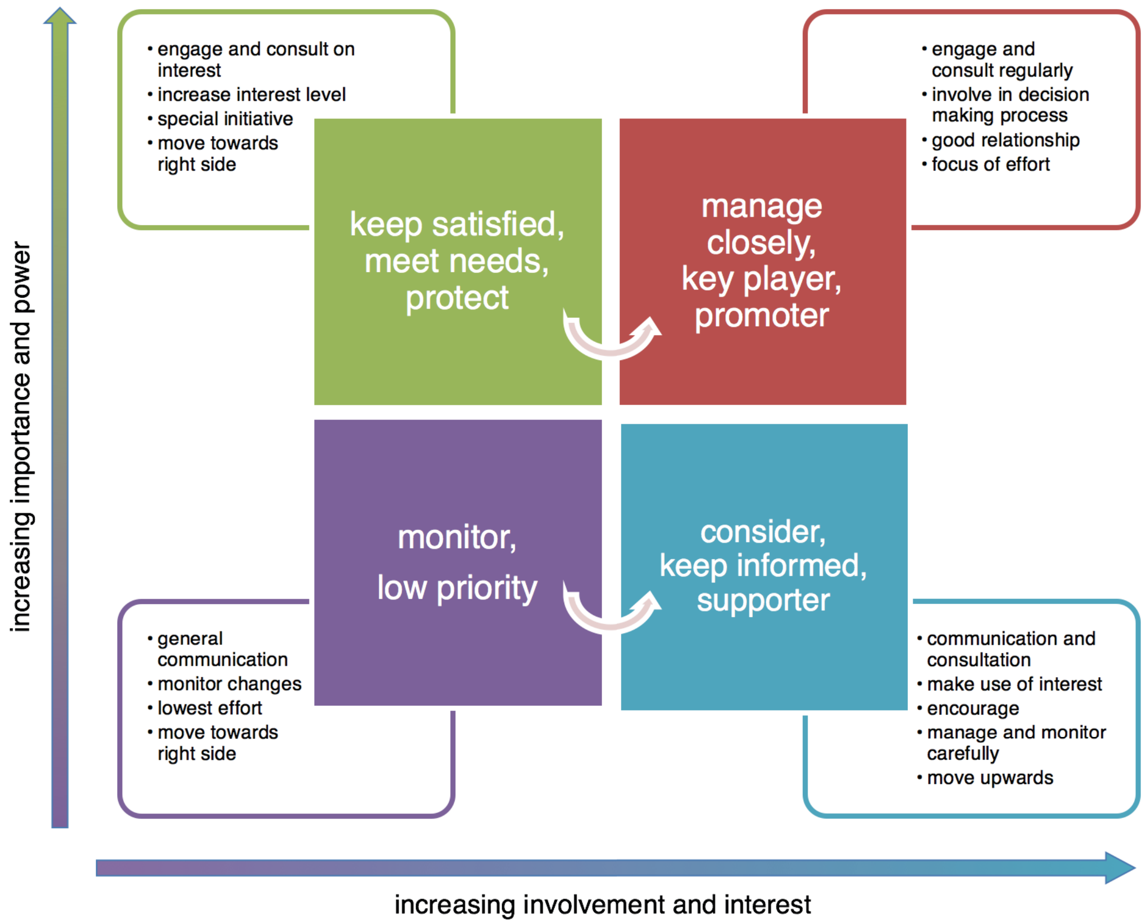


Figure 14: Stakeholder matrix

Analysing interests of stakeholders and elements of communication between them

In order to analyse the way of interaction of stakeholders, their interests should be known with regard to necessary actions for planning and implementation of iSaS. Actions are defined by the tasks that need to be executed, and by the stakeholder or actor who is responsible for performing the actions.

Questions can be asked to define and analyse tasks, actions and responsibilities:

- What needs to be done? (task description, physical or mental activity, …)
- Where will it be done? (district, building, room, …)
- Which means are available? (tools, technical equipment and plants, computer, …)
- Who is doing it? (stakeholder, executing person or organisation, …)
- When will it be done? (time of action, low / high priority, …)

The following Table 4 summarizes and structures the questions in form of a simplified planning tool by defining tasks, stakeholders and prioritising actions.

Table 4: Task & action matrix for analysing tasks, responsibilities and action

task 1, 2, …, n	**description** 1, 2, …, n	**location** 1, 2, …, n	**means** 1, 2, …, n	**stakeholder** 1, 2, …, n involved, yes / no			**priority** 1 (low) - 5 (high)	**action**
				1	**2**	**n**		
task 1				☐	☐	☐	☆☆☆☆☆	
task 2				☐	☐	☐	☆☆☆☆☆	
…..				☐	☐	☐	☆☆☆☆☆	
task n				☐	☐	☐	☆☆☆☆☆	
examples:								
residents' option workshop	defining suitable technological option for iSaS	bag (district) 7	presentation tools and speakers	☑	☑	☐	★★★★☆	organise workshop with moderation
market for construction material	analysing market for construction material and compare with import options	project office	network of suppliers	☑	☐	☑	★★☆☆☆	ongoing activity until implementation by project management

iSaS require a high level of communication. With such simple tools like the stakeholder matrix and the task & action matrix, the management of communication needs can be handled in a comprehensively arranged way.

Suitable methods for participatory planning

For the execution of participatory planning tasks and action it is advisable to rely on available and established tools. For iSaS the “*Community-Led Urban Environmental Sanitation Planning”* (CLUES) and “*Community-Led Total Sanitation”* (CLTS) are recommended, as these tools were particularly developed for areas, which are fitting to the framework conditions of iSaS (see Table 2). CLUES and CLTS (see Figure 15) are training guidelines, which are publicly available and frequently used (Kar, 2010; Kar & Chambers, 2008; Ulrich, 2011).

A further tool “*The Three Star Wash Approach In Schools*” is described in (Stäudel et al., 2014; UNICEF & GIZ, 2013). Such a tool is particularly helpful to make children becoming part of the participatory planning as well. As a complementary method, this is particularly useful to trigger behaviour change among the target population.

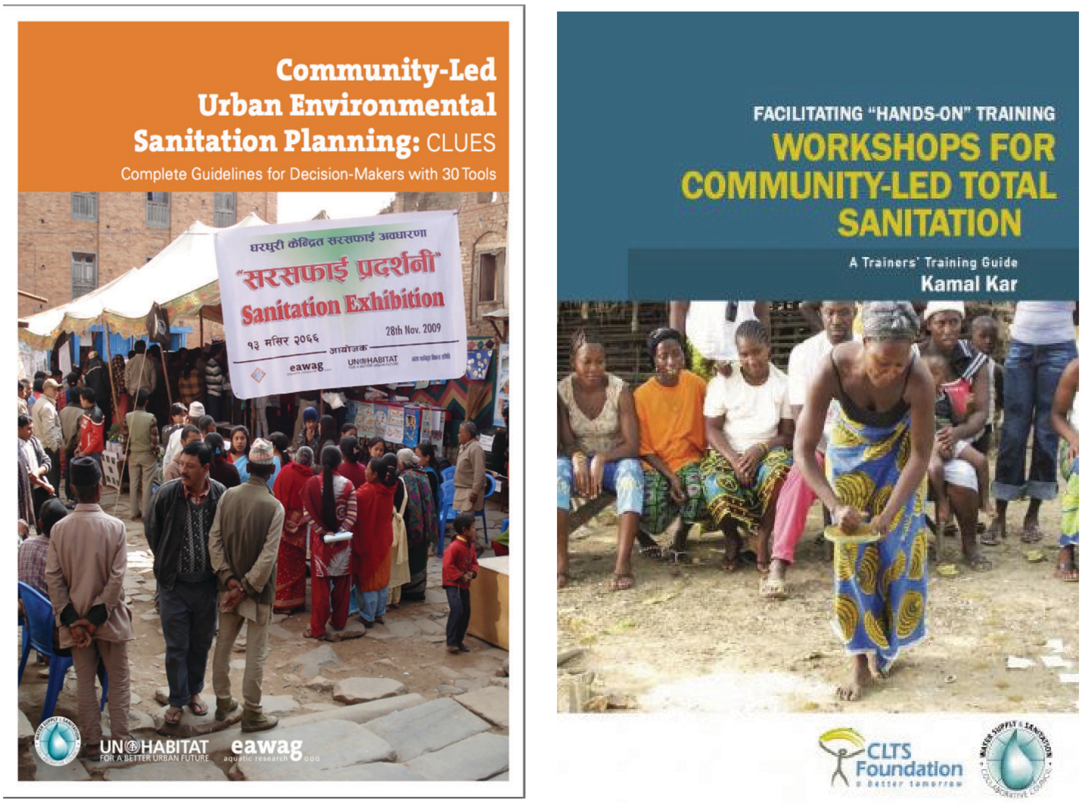


Figure 15: Tools for community participation in sanitation infrastructure – Examples CLUES and CLTS

The concept *“Sustainable Sanitation and Water Management Toolbox”* from seecon GmbH provides another useful tool towards a holistic approach for sanitation. It intends to consider the influence of human activities on the entire water and nutrient cycle by linking sustainable sanitation, water management & agriculture (seecon GmbH, 2016).

Government, service provider and formation of operational structures

The complexity of integrated systems requires a level of structure and organization, which can only be provided by a state with a minimum of political stability and legal framework. The delegation of public services to **small and medium enterprises (SME)** as service providers or **public private partnerships (PPP)** is often considered as a useful measure to ensure reliable operation of infrastructure systems.

In reality these measures show different results of success. In Alfen et al. (2009) and UNESCAP (2010) it is shown, that governmental support is crucial to create a successful PPP project. This can only be achieved by detailed assessment (feasibility studies) and planning, and requires a fair amount of expertise in managing larger projects. In Harbach (2011, p. 64) it is stated, that know-how and sufficient financial means are the most critical conditions for sustainable and successful water infrastructure projects.

iSaS has to support the process of forming public and or private organisations, but it is recommended to include experienced advisors depending on the scale and complexity of the infrastructure project.

The provision of a consistent legal and financial framework is vital for allowing SMEs to operate as service provider. But even if framework conditions are good, the formation of SME may still be difficult if the understanding of entrepreneurship is low in the target population.

Example – the franchise model in the water sector:

An idea is to **motivate SMEs to operate under a franchise umbrella of integrated sanitation**. The franchising model is often discussed in SWM projects, usually with the aspect to include the local know-how of wastepicker communities from the informal waste sector to become part of the formalised waste management system. The goal hereby is to enhance the reliability of services by equally strengthening the local economy. In the water sector, the idea of franchising is less common, but has been examined in several pilot projects with mixed results, such as in Kenia (Lüthi, Panesar, et al., 2011), Cambodia (WSP, 2012) and South Africa (Harbach, 2011).

In a franchising business model, the franchisor (carrier of know-how) and franchisee (local enterprise) can mutually benefit from each other’s expertise. The franchiser ideally profits from the higher motivation and the higher acceptance level due to better local integration of the local enterprise.

In (Prasad, 2006, p. 25) it is stated, that *“the important thing is whether the services provider has incentives and how accountable are they to the general public.”* Political influences into business operation and management of the franchisee should be kept at a minimum and defined level. Eventually the performance of a private company is depending on the local capacities to operate in a stable economic environment in order to sustain a high level of service.

Clear benefits of private sector participation could so far not be proved according to (Prasad, 2006), whereas in (Harbach, Rudolph, & Block, 2011) it is affirmed, that the contribution of SMEs and the private investors is essential to reach a substantial improvement in the water and sanitation sector. Certainly, the approach of private sector participation needs to be further pursued, as state organisations alone do not have sufficient capacities to face the present challenges.

An investigation from the Netherlands gives some ideas about problems, that may occur with forming local SMEs under the franchise umbrella, based on (Masurel & Nijkamp, 2009):

- unfamiliarity with the idea to build up a profitable company in a western manner based on a business model, which has sanitation as a core process
- low institutional orientation
- missing useful purpose
- economical risks
- level of legal formality too high

- distress of losing independence
- lack of understanding and cultural background
- lack of acceptance by own local population.

Nonetheless, **informal businesses** can often be found in the field of sanitation. Usually they are born out of poverty in gaps left by the government and in grey zones of legislation. Governments let them operate as long as the informal sector is filling out gaps without disturbing regular governmental activities. Therefore, it can be stated, that the initial impulse for establishing a formalised business in the sanitation sector has to come from the government.

Often municipalities and local governments respectively are willing to establish such a business, but they depend on decisions made / and the allocation of budget by the central national government, which is for instance the case in Mongolia, Cambodia and Ethiopia (own experience).

However, regardless of the level of centralisation of a national administration, **it lies within the responsibility of the government to provide the legal and economic framework as basic conditions**. These conditions can come in form of suitable legislation and reliable exercise of rights, for instance, the right to collect fees and other sources of income to cover costs and a suitable definition of roles and responsibilities. Here, iSaS have a high potential to serve as a mediator.

B.3.7 Summary and definition iSaS

Integrated Sanitation Systems (iSaS)

contain

- material - flows: urine, faeces, greywater, drinking water, rain and service water
- organic waste (e.g. green waste, kitchen waste, manure)
- other potential co-substrates (e.g. sewage sludge, part-material-flows from industry, food production and others)

consider techniques of

- collection
- transport
- treatment
- reuse (avoid disposal / discharge → regain resources)

combine

- the three levels
  - material-flows / energy-flows / technology
  - monetary-flows / economy
  - communication-flows / capacity development / structures

and

- existing infrastructure with new infrastructure, technologies and processes

into one holistic concept for sustainable infrastructure.

iSaS aim

- to intermediate between stately organisations and users (top down ↔ bottom up)
- to preserve / improve public health
- to reveal unused potential of cost-effectiveness
- to improve resilience to demographic and climate change
- to enhance flexibility by inclusion of new technologies
- to integrate with existing and future infrastructure on local / regional scale.

B.4 Conclusion

It is undoubted, that infrastructure systems for growing and dynamically changing cities require different approaches towards sanitation. Historically, it has already been known more than 150 years ago that the diversity of human living environments needs adapted sanitation systems, which are particularly developed for and adapted to the specific context. This also requires different technical and organisational solutions, which are not directly comparable, but have equitable eligibility depending on their context of application.

The prevailing paradigm of conventional sewage systems decelerates urgently needed innovations in the field of sanitation. It could be shown that there is no right and wrong in terms of sanitation systems, as a final answer can only be defined by failure or success, break down or functioning, rejection or acceptance.

Therefore, the driving question behind the development of integrated sanitation is how different approaches can actually work together and complement each other in order to benefit people and environment in the most efficient way. Integrated sanitation demands, “to *renew and refresh the mind”* in terms of sanitation, so that different parts are closely re-connected and can work successfully together.

This requires a conscious decision towards a more interconnected way of thinking of educators, planners and decision makers on different levels. Integrated sanitation systems represent an idea for this conscious interconnected way of thinking and acting towards infrastructure solutions. The higher the level of complexity is, the deeper the level of integration needs to be elaborated.

The complexity of integrated systems requires a level of structure and organization, which can only be provided by a state with a minimum of political stability and legal framework. Essential criteria and indicators, which need to be fulfilled to provide the minimum framework conditions for iSaS, have been formulated in this chapter.

In order to take local circumstances into account, iSaS can be structured in three descriptive “levels”:

1.) Material-flow, energy-flow, and technology, that allows for a flexible and adapted value-added processing of separated material-flows. Existing conventional infrastructure systems have to be combined with new technologies of resource-based approaches. Currently new technologies still need to mature with regard to user acceptance and operational capability.

2.) Monetary-flow and economy, which shall reveal unused economic potential and enhance cost-effectiveness. Through value added reuse the direction of monetary-flows can be partly reversed in the system. Despite obvious costs, such as investment or administration, material and energy-flows are expressed in their current market value within the system. Maintenance is a crucial factor to ensure the continuous and damage-free operation of the system.

3.) Communication-flow, stakeholders and structures, which describe tools and procedures for communication and interaction between stakeholders. iSaS have the role of a mediator between the governmental top down approach and grassroots-driven bottom up approach.

A high level of corruption can easily prohibit the implementation of an infrastructure system. iSaS cannot prevent from such problems, which are usually immanent in the respective society. With the lack of functional and efficient administrative structures, the level of communication-flows of iSaS gets an even bigger role in the iSaS approach.

Service providers, regardless of being public or private companies, need the positive engagement of the legislator and administration, who have to create the stable framework for operation. However, by creating public awareness and transparency **iSaS have a potential to mitigate the negative impact of corruption**. The level communication-flow has to be regarded as equally important as the technical side of iSaS.

C Integrated sanitation in Mongolia – the case example of Darkhan

This chapter summarizes the results of the pilot project "Integrated sanitation in Darkhan, Mongolia" as part of the IWRM MoMo2 (Integrated Water Resources Management (IWRM) – Model Region Mongolia, Phase 2) project. In theory, IWRM is „a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP & INBO, 2012, p. 10).

Since 2006 the IWRM MoMo project has been working on the investigation and implementation of strategies towards an IWRM for the Kharaa catchment area as a model region for Mongolia and Central Asia. A particular focus lies on the city of Darkhan and its surroundings (BMBF, 2009; GWP & INBO, 2012; Menzel, Hofmann, & Ibisch, 2011).

The research group of the department of Urban Water Management and Sanitation at the Bauhaus-Universität Weimar was leading the part-project *"Integrated Urban Water Management and Sanitation"* in the country's 2nd largest city, Darkhan, in northern Mongolia. The part-project focused on problems and solutions for sanitation related to increased urbanisation tendencies as well as economic growth and increasing population.

The development of an *integrated sanitation system for **ger areas*** (which are yurt settlements at the city fringes) was the practical part of the research work of the author of this dissertation. The results of the research are summarized in the following chapter, which are further on the basis for the development of the mathematical iSaS model.

C.1 Project area in Mongolia, the city of Darkhan, and project background

Mongolia is a landlocked country in Central Asia, neighboured by Russia and China. With an area of 1.56 million km^2, it is roughly 4 times the size of Germany. In January 2015, Mongolia celebrated the birth of its three-millionth citizen, but it remains the country with the lowest population density in the world (1.9 people/km^2). With an average elevation of 1,528 m it belongs to the countries with the highest average elevation above sea level in the world.

The largest city is the capital Ulaanbaatar (UB, *Mongolian: Улаанбаатар*), which is home to almost half of Mongolia's entire population. UB is the political, cultural and economic centre of the country and is governed as an independent provincial municipality. It also holds the record of being the coldest capital in the world, is listed as the city with the highest air pollution level and ranks among the top 15 most polluted cities in the world (Numbeo, 2016).

With the challenges UB faces, it equally stands exemplary for the other – but considerably smaller - Mongolian urban centres, such as Erdenet, Darkhan, and Choibalsan. The country is divided in to 21 administrative provinces or *aimags* (*аймаг*), which have been established since the Mongolian Revolution of 1921. Each aimag is subdivided in to several districts and each town is subdivided in to sub districts or *bag*. Despite the level of administrative diversity, Mongolia remains a country with predominantly central financial control and central political decision-making at a national capital level (Sigel, 2012).

Figure 16: Map of Mongolia and project location Darkhan based on data from openstreetmap.org

The project area of MoMo2 is the hydrological river basin of the *Kharaa* river, which is a tributary to the *Selenge* river and Lake Baikal in Russia. The Kharaa river basin extends across the three aimags Selenge, Töw and Darkhan-Uul. Darkhan (Дархан) is the capital of Darkhan-Uul province in northern Mongolia, where the pilot-project *"Integrated Sanitation in ger areas"* was located.

C.1.1 Mongolia – a country in transition

Mongolia is a transition country, trying to overcome the heritage of many decades of socialist rule and state-directed economy. Still the country is struggling with the rapid change of political and economic values, weak economy, and the deteriorating as well as missing infrastructure.

Equally Mongolia undergoes deep societal changes from a nomadic culture towards a modern Asian urban life style. The country tries to balance traditional values with unrestricted liberties of free markets. The willingness to achieve higher living standards comes with strong tendencies of urbanisation and rural depopulation (see Figure 17).

Figure 17 a.) Open landscape with untouched river
b.) Rapid urbanisation and growing city fringes in ger areas in Ulaanbaatar

One characteristic of this urbanisation is a lack of water, often worsened by insufficient capacities for the distribution of the low amounts of available potable water. Particularly in the rapidly growing peri-urban districts or *ger areas*, the (sometimes complete) absence of infrastructure is a severe problem faced by all urban areas in Mongolia. This problematic situation is equally shared with many regions in other countries of Central Asia with similar history and similar geo-ecological conditions.

C.1.1.1 Extreme climate as a challenge for infrastructure development

In many ways, Mongolia is an extreme country, which is likewise the case for its climatic conditions. Mongolia has an extreme continental climate with long, cold winters and short summers. Most of its annual precipitation falls during the short summer period June, July and August. Temperatures in Mongolia can range from below -40 °C in winter nights to +40 °C in the Gobi Desert in summertime respectively. Large parts of Mongolia are covered with discontinuous permafrost. The average annual temperature of UB is -2.9 °C with a frost-free period of less than 3 months.

The **climate in the project location Darkhan** (see Figure 18) is slightly more moderate compared to UB. With an altitude of around 1,300 m UB is roughly 600 m higher than Darkhan, which lies at an altitude of 718 m. The temperature in Darkhan averages at -0.6 °C. Precipitation is also higher in the northern parts of Mongolia. This results in a summarised average rainfall of 309 mm over the year. February is the driest month of the year (2 mm precipitation) and July is the wettest month with an average rainfall of 83 mm. July is also the warmest month of the year with around 19.2 °C. The lowest annual average temperature of -24.7 °C can be found in January (Climate-Data.org, 2016). The period with average temperatures below 0 °C lasts from October to April, whereby the freezing level reaches below a depth of -2.5 to -3 m.

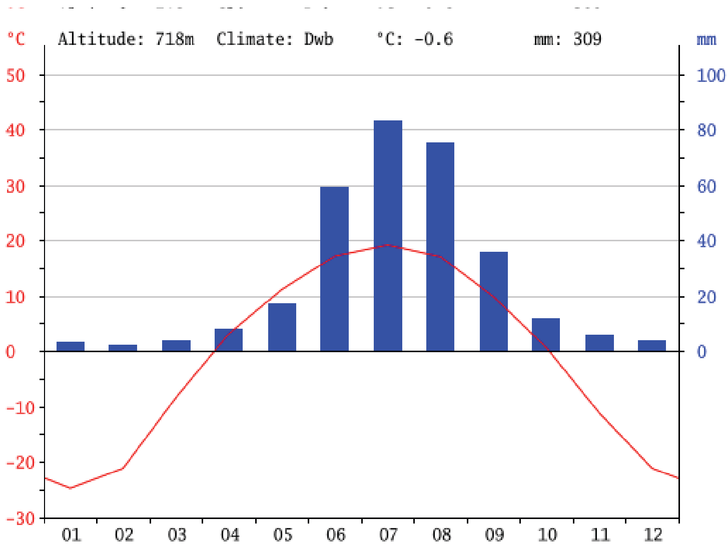


Figure 18: Climate graph of Darkhan according to (Climate-Data.org, 2016)

The climate in the Darkhan region is classified as Dwb (continental, winter dry, minimum 4 months warmer than 10 °C) climate according to the Köppen-Geiger-system and slightly warmer than most of the other parts of Northern Mongolia. In fact, it is one of the very few regions in Mongolia, where industrialised agriculture is practiced since the late 1950s (Schweitzer, 2012, p. 14).

Mongolia is strongly affected by global climate change, whereby the effect varies in strength throughout the seasons. In the last 70 years, the average temperatures in winter (+3.6 °C) were rising faster compared to spring (+1.8 °C), summer (+1.3 °C), and autumn (+0.5 °C) according to (Batimaa, Myagmarjav, Batnasan, Jadambaa, & Khishigsuren, 2011, pp. 2, 3). Equally the change of precipitation rates has been described. For the Kharaa river basin the tendency of higher temperatures and changing precipitation, combined with an overall decrease of the river discharge, has been confirmed in (Hofmann, Hürdler, Ibisch, Schaeffer, & Borchardt, 2011). The changes vary across the country in location and time and generally have the tendency of precipitation increase in winter and decrease in summer.

It is obvious, that many problems with regard to water quantity and quality result from Mongolia's (semi-) arid climate and its heavy climate fluctuations combined with climate change. Increasing economic developments, particularly in the mining and agriculture sector, and out-dated infrastructure can be named as other main influencing factors caused by human activity (Horlemann & Dombrowsky, 2010).

All these aspects have a significant impact on technology choice and economics of infrastructure projects. The climatic conditions must be well regarded in planning, implementation and operation. For instance, sewers are usually built in a depth of -4.50 m in Mongolia. Special measures have to be applied to ensure the durability of infrastructure systems throughout their construction phase and their operational lifetime.

C.1.1.2 Historical background of infrastructure development and society

Until recently the vast majority of the Mongolian people were nomads. The nomadic life was determined by the needs of the livestock, which were the main foundation of survival. People had to move their cattle to the most fertile parts of the land in order to be able to survive in the harsh steppe. The first more durable settlements formed around Buddhist monasteries in the 17th century. These settlements were still moved from time to time and were mobile monastery-towns rather than fixed settlements. Eventually this had fundamentally changed with the socialist revolution in 1921 and the proclamation of the Mongolian People's Republic in 1924. In the following 7 decades, the Soviet Union had strong influence on Mongolia and determined the politics of the communist regime.

Figure 19: "Modern" nomadic life in Mongolia

Since the 1960's collectivism and state-directed economy were built-up under Soviet pressure and with Soviet support. From then on, the prerequisite for settled life in an urban environment was created by the construction of typical Soviet-style satellite towns.

The urban areas were equipped with all essential infrastructure facilities, such as administrative buildings, schools, kindergartens, hospitals, universities and research facilities, and industrial production areas. The towns were equally outfitted with supply and disposal systems, such as water supply, long distant heating, electricity, solid waste, and wastewater collection and treatment. The high level of infrastructure development – even if artificially forced by the Soviets

– required an equally high level of skilled labour and educated experts to operate the facilities. The success of the socialist education policy resulted in one of the highest global literacy rate among adults of almost 98 %.

The shift from a socialist to a democratic system has caused fundamental changes in the Mongolian society in the late 20th century. Under socialist rule, Mongolia's economy depended on more than 90 % of trade with the socialist brother states and foreign aid from Russia. After the political change in the beginning of the 1990s the dependency resulted in a devastating economic crisis. For some years, the economic crisis temporarily reversed the trend of rural depopulation, followed by a decline of the population, and a resumption of nomadic lifestyle. An extensive overview (including social, economic, and ecologic aspects) into history and recent development of the Mongolian society is given in (Grunert & Stolz, 2009).

C.1.1.3 Economic and societal changes in contrast to infrastructure development

Since the beginning of the 2000s the economy in Mongolia experienced a strong upturn with annual growth rates of, in average, 9 % GPD. In the year from 2010 to 2014 the poverty headcount ratio (% of population below the national poverty line) declined from 38.8 % to 21.6 % according to data from The World Bank DataBank (The World Bank, 2016).

Along with the economic development, rural-to-urban migration accelerated. Nowadays around ¾ of the Mongolian people live in urban areas. The tendency of rapid urbanisation is unbroken. As a result of this development, severe environmental and social problems are affecting not only the capital UB (Sugimoto, Kawagishi, Kitano, Gonchigbat, & Hirota, 2007), but all other major cities in Mongolia as well.

Despite the strong economic growth and the rise of GDP per capita, the development of sanitation infrastructure is stagnant since almost 25 years. The demographical development of Mongolia (total, urban, rural) and the ratio of people with access to improved sanitation and water supply are displayed in Figure 20. While the GDP (at market prices) almost quadrupled since 2006, and for instance the mobile phone subscription rate rose from 30 % to almost 110 % in the same period, **hardly anything happened on the sanitation and water supply sector, despite many pilot projects in ger areas in Mongolian cities**.

According to the data from The World Bank (The World Bank, 2016), in absolute numbers more people have gained access to sanitation and water supply, but it is difficult to interpret the available data. In (Dolgorsuren, Bron, & van der Linden, 2012) some more detailed figures are given, which support the trend to slight improvements, but the displayed data is not consistent for the observation period of the last 10 years.

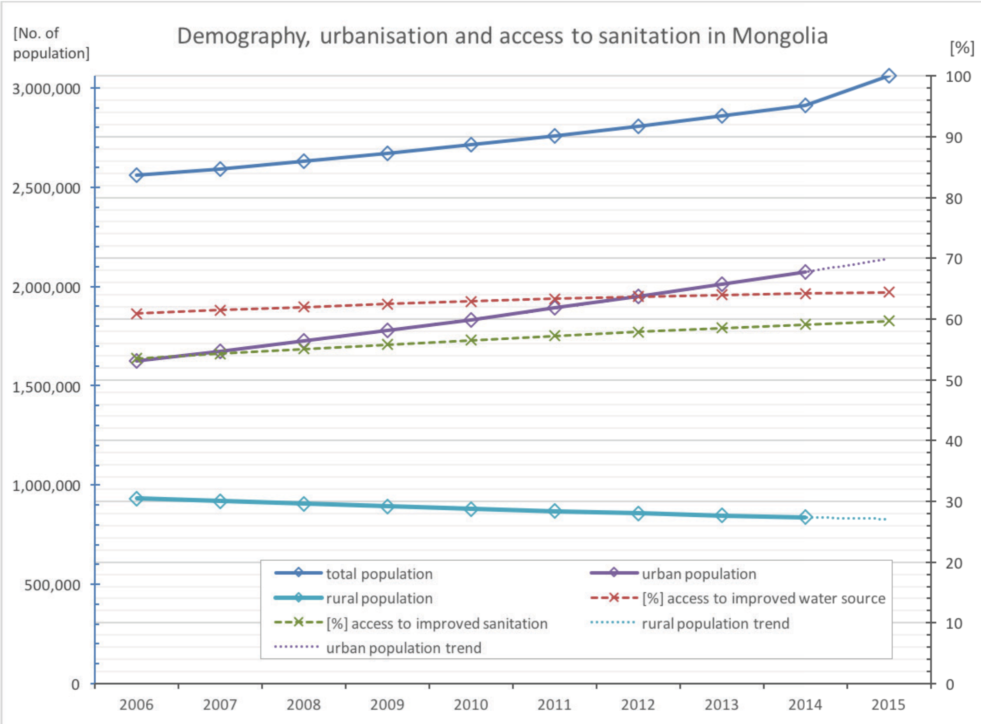


Figure 20: Demography, urbanisation and access to water & sanitation in Mongolia, 2006 – 2015 based on data from The World Bank DataBank 2016

There are no sources, which show how much money has been invested in the water and sanitation sector. Also, the Mongolian Statistical Yearbook does not record numbers, which would allow to draw conclusions about the activities in infrastructure development (National Statistical Office of Mongolia, 2013).

It is assumed, that the rise of the absolute number of people with access to sanitation and water supply is mainly related to the on-going urbanisation process and less related to investment into urban infrastructure systems: People move into ger areas, where some sort of basic supply is already existing (e.g. water kiosks) and therefore count in the statistics, rather than being affected by measurable improvements of the situation.

The main reason for the lack of improvement in this area is obviously related to the complexity of the situation combined with an expectation to find a simple solution. It is known, that conventional sewage systems are too expensive and not feasible in this extreme climate in combination with the predominant urban settlement structures in ger areas (Karthe et al., 2016). However, some development programs still promise the implementation of this technology as a solution in a questionable way, as has been done recently on the website of the Asian Development Bank (ADB, 2016).

In personal conversations, some decision-makers and experts affirmed the wish to transform ger areas into modern housing types, while equally acknowledging that ger areas will persist unchanged for at least 30 years or more. Further on the experts stated, that it is not clear which type of infrastructure is useful, and how to finance infrastructure in the proposed new housing areas. The combination of challenging governmental structures, centralised allocation of money, and a lack of know-how can be named as reasons for postponing necessary decisions with regard to investment into urban infrastructure systems (Source: personal conversations with local experts in UB and Darkhan 2010-2013).

The biggest part of the infrastructure in place has been built between 1960 and 1990 and is in a deteriorating state. The status quo of urban infrastructure systems in Mongolia therefore remains mainly unchanged since the Soviet period and only minor improvements have been made. An inventory of the state of water supply and wastewater infrastructure in Mongolia is given in (Dolgorsuren et al., 2012, p. 383ff and 523ff.). The situation is portrayed in a more descriptive way at the example of the city of Darkhan in chapter C.1.2.

C.1.2 Darkhan city – background and state of infrastructure

The city of Darkhan (Mongolian for "blacksmith") is located around 200 km north of the capital Ulaanbaatar. It is the capital of Darkhan-Uul aimag. Darkhan was built starting in 1961 (old part) and 1965 (new part) by the Soviets as an industrial town. The city centre consists of strictly planned apartment houses (see Figure 21), surrounded by rapidly growing peri-urban districts or ger areas (see Figure 22). Darkhan is the main industrial centre in Northern Mongolia with a big range of economic activities, such as agriculture, tanneries, mining, steelworks, cement production, construction, and more (Battsengel & Janzen, 2010).

Population of Darkhan

According to the latest available statistical data form 2012 (National Statistical Office of Mongolia, 2013), Darkhan-Uul has a population of approximately 93,900 inhabitants, whereas 78.9 % (21,000 households) are counted to live in urban areas and 21.1 % (5,300 households) in rural areas, respectively. Newer sources estimated 96.428 citizens for Darkhan and around 180,000 inhabitants in the metropolitan area for the year 2013 ("Дархан хот — Википедиа нэвтэрхий толь," 2016).

As data about the official population number is contradictory, Darkhan ranks sometimes as the 2nd or 3rd largest city in Mongolia. It is here assumed, that the number has reached 100,000 inhabitants in 2015. According to verbal information given at a workshop in April 2013 in Darkhan, the ratio of people living in ger areas / apartment houses rises from 1:1 to 1.5:1 (or 60 % ger area / 40 % apartment houses). For **all further considerations,** the population is assumed with a total number of **100,000 citizens, 60,000 in ger areas, 40,000 in apartment houses.** The people in ger areas live on privately or rented plots of land, so-called *khashaas*. Sometimes several families share one khashaa and data on family sizes also vary. In order to simplify the further explanations **10,000 khashaas in ger areas** are assumed.

Urban structures and state of urban water infrastructure - examples

Equally to all new urban areas in Mongolia, Darkhan has also been equipped with broad infrastructure systems, which were typical for that time in the Soviet Union (as mentioned above in Chapter C.1.1.2): supply with electricity, central drinking water, community heating, garbage collection, wastewater sewers and a central WWTP with activated sludge treatment. In contrast to the central urban areas, ger areas have a complete lack of planned infrastructure. The following two pictures display the predominant housing types in urban areas in Mongolia:

Figure 21: Planned urban structures in Darkhan based on Soviet building types

Figure 22: Ger area in Darkhan without any planned infrastructure

Since the Soviet time not much has been invested into the city's infrastructure, which is nowadays significantly damaged and partly non-functioning. Most of the existing facilities, such as the WWTP, pumping stations, power plant, and others appear with an interesting character of a museum, but obviously, the impact on the city is serious in many ways.

With a loss of more than 40 % in the drinking **water supply** network, the water consumption of people living in apartment buildings is as high as 265 l/cap*d. Further reasons for the high-water consumption are low water connection fees combined with "flat rates" for cold and warm water.

Apartments get gradually equipped with water meters, but positive economic and ecological effects remain low, as long as hot water from the community heating is available at lump sum prices (BMBF, 2009).

The **wastewater system** is in an even worse state of deterioration. The separate drainage and sewage systems show significant damage resulting in less service reliability by at the same time increasing operational costs. Due to **uncontrolled loss** through broken and wrongly connected pipelines, a significantly lower portion of the total produced wastewater is actually reaching the wastewater treatment plant. Further on, significant industries such as the meat factory, tannery, and power plant are not (or not anymore) connected to the **central WWTP** and discharge the untreated wastewater into the next receiving water.

The existing WWTP has severe structural damages and can hardly be operated anymore due to a lack of spare parts and missing maintenance. Just some parts of the mechanical treatment steps of the WWTP are still functional, whereas the activated sludge process consumes huge amounts of energy and money, not to mention, that effluent standards cannot be met (BMBF, 2009). Examples of the situation are shown in Figure 23 a.) and b.).

Figure 23 a.) Damaged clarifier of central WWTP b.) Discharge of untreated industrial wastewater from tannery towards Kharaa river

Sewage sludge is deposited in open, unsealed ponds next to the wastewater treatment plant of Darkhan and causes a strong smell during summer time, as well as contamination of soil and groundwater. In addition to that, the resources contained in sewage sludge (nutrients, energy) are wasted (Bruski, 2015, p. 19 f.).

The identified problems with the current urban wastewater infrastructure and the lack of adequate sanitation services can be summarized as follows:

- water losses in the whole water distribution system including the indoor installations in the apartment buildings due to a lack of maintenance
- insufficient treatment (if at all) and partly direct discharge of industrial wastewater to the Kharaa river
- missing equipment in wastewater pumping stations

- central treatment plant with bad quality of concrete and equipment
- missing excess sludge treatment as excess sludge is just dumped in collection ponds near the treatment plant
- pollution of receiving waters, which are used for irrigation & as dew ponds (see Figure 24)

Figure 24: Pollution of small receiving water through effluent of WWTP

The rehabilitation of the whole system including a new WWTP is needed in the near future. In particular, the new treatment plant has to reduce the loads of phosphorus and suspended solids in the effluent extensively. A good microbiological quality has to be achieved as well, as the receiving river Kharaa serves as a drinking water source for cattle (dew pond) and humans further downstream. These measures also need to be undertaken with regard to the fulfilment of transboundary governmental contracts, as the Kharaa river contributes to Lake Baikal in Russia (Londong, Städel, Rost, Bruski, & Hartmann, 2014).

On a national legislative level, general measures are specified and goals are defined in the *“Water” National Programme* (Parliament of Mongolia, 2010) and standards for wastewater treatment are existing, such as “*MNS 4943 Effluent treated wastewater. General requirements”.* Yet, the **standards are not evidence-based** and **do not represent recent scientific findings**. The respective political, legal and administrative framework as well as an overview of related Mongolian standards (MSN) is described in (Sigel, 2012, p. 45 ff.).

C.1.3 The sanitary situation in ger areas – Darkhan as example

The situation in ger areas in Darkhan is exemplary for all towns in Mongolia, and beyond in comparable regions in Central Asia. Surrounding the strictly planned and well-equipped satellite town Darkhan, ger areas have developed over the last decades – an on-going process. In all major aspects of infrastructure, the ger areas are in stark contrast to the town centres.

Water supply

Drinking water is mainly supplied through water kiosks (little shops for water), where residents buy water in small quantities. The transport of the water to the Gers and houses is organised individually in cans and barrels. As a result the **water consumption is very low** and down to **8 - 10 l/(cap*d)** in average (Basandorj & Altanzagas, 2007), which is just above the minimum requirements given by the World Health Organisation (WHO) of water supply for survival in emergency situations (which is 7.5 l/(cap*d)). The WHO recommends minimum quantities of 30 to 50 l/(cap*d) in order to meet basic needs of hygiene and consumption (Howard, Bartram, & WHO, 2003).

Figure 25 a.) and b.) Water kiosks and transport of water in ger area in Darkhan

The water kiosks are supplied either by water trucks (unreliable) or increasingly they are connected to the central drinking water supply system (DWSS). In districts near the floodplain of the Kharaa river, where the ground water table is close to the surface, often private wells are used (see Figure 26). Both water sources are not safe with regard to hygiene and in some cases also unreliable (e.g. broken water truck, frozen well).

In particular, the **groundwater** from open wells is often **contaminated with pathogens**, as faecal matter from unsealed pit latrines infiltrates in the soil and water bodies. The prevalence of illnesses such as certain diarrhoea and other waterborne diseases is known (Sigel, 2010), but needs to be further monitored in order to gain measurable data (Borchardt et al., 2012).

In Darkhan the residents are increasingly aware of the problem with waterborne diseases. However, if a family cannot afford to buy piped or trucked water from the water kiosks, they are forced to fall back on this water source.

Figure 26: a.) Unprotected well accessible to cattle and b.) adjacent to typical latrine

Sanitation

Simple unsealed pit latrines are used for defecation. The picture shown in Figure 26 b.), which was taken some meters beside the unprotected well (Figure 26 a.), displays a typical example for the predominant form of sanitation in ger areas.

Due to the extreme climate in Mongolia, many specific problems are related to this type of sanitation, which exceed the usual problems with hygiene, comfort, and stability: As biological degradation as well as infiltration rates are very low, the pits need to be replaced more often and re-established at a new location within the private real estate. Particularly in wintertime these latrines are dangerous to use, as the slab freezes over and becomes slippery.

Further on the **latrines become unusable**, when frozen faecal matter piles up above the latrine slab. Therefore, children often prefer to openly defecate in the courtyard. In UB and Darkhan some private companies deal with unusable latrines, but the difficulty of the situation is hard to imagine, if it is not experienced personally. The private real estates also lose value, due to the ongoing **soil contamination through the pit latrines**. Many properties are completely contaminated and have no space to build new latrines.

Recent investigations clearly indicated that simple pit latrines do not offer a solution, as this technology involves strong smell, health risks, high costs for emptying (uses a lot of water, road access and vacuum truck required), risk of collapse (if unlined), and possible overflow during floods in summer (Ulrich, 2010).

At this point it has to be critically mentioned, that such type of latrines (if equipped with a covering slab) are already considered as an "*improved*" form of sanitation and count in the statistic of the Joint Monitoring Programme (JMP) of UNICEF and WHO in the indicator *"% of population with access to improved sanitation facilities"* (compare Figure 20). Because of this, the interpretation of such data is difficult, as qualitative statements about the real sanitary needs of a population cannot not be derived from such indicators.

For the Darkhan case, a socio-economic study (household survey) has been carried out in 2009. In this study detailed data about water supply and sanitation, as well as income situation, social data and administrative structures in the project area in town sub-district (*bag7*) can be found (Sigel, 2010).

The identified problems with the lack of adequate sanitation in ger areas can be summarized as follows:

- lack of hygiene and comfort
- simple pit latrines with fill and seal operation
- infiltration of faecal matter
- soil and ground water contamination
- loss of usable ground on the estate

Drainage and road infrastructure

The situation in ger areas concerning drainage and roads has to be mentioned briefly, as it significantly influences the technological design of water supply and sanitation systems and influences operation and maintenance. The quality of roads is generally poor and **dirt roads are predominant** in bag7. As can be seen in Figure 27, even off-road vehicles may have difficulties to access ger areas and put strain on material and engines, particularly in the months with rainfall and in wintertime. **Drainage canals**, which were built in Soviet times, are insufficient, often blocked by garbage, and **partly broken**, which leads to flooding in parts of the town.

Figure 27: Lack of drainage & damaged road in bag7

Solid waste situation

With regard to solid waste collection and disposal the situation is equally challenging and unsatisfying. Public waste services in ger areas are unreliable and get activated mainly after residents request the administration to take action. **Illegal open dumping and burning** of mixed waste **is prevalent** in areas without sufficient service. The concept of waste separation is not practised in Mongolia.

The solid waste situation was not in the focus of the research in Darkhan. However, the issue of reliable waste collection services and a clean living-environment has a significant value in the perception of the local population. This has been confirmed in studies and workshops with experts and residents during the field research in Darkhan (Böhm, Lauckner, & Seyfarth, 2013; seeconsult GmbH, 2011; Sigel, 2010).

C.2 Pilot project "sanitation in ger areas" in Darkhan

The appearance of two totally different, yet in itself coherent, urban structures side by side (planned centres and ger areas), is quite unique to Mongolia. The two distinctive structures, with hardly any transitional development stage in-between, offer interesting opportunities and simplify the approach for development.

The pilot project in Darkhan is not the only project in Mongolia that targets the difficult sanitary situation in ger areas. In fact, sanitation in ger areas is a topic that has received a lot of attention and is reasonably high on the priority list of NGOs and development organisations. This can be seen in the high number of studies, reports and pilot activities, most of them carried out in UB (Peters, 2012; Uddin, 2015; Ulrich, 2010). The particular of the pilot project in Darkhan is the clear focus on an integrated approach right from the beginning.

C.2.1 Systemic approach and objectives of the pilot project

The challenge was to create the system in a way to be fully adapted to the local framework conditions, like the lack of water, missing and existing infrastructure respectively, as well as the extreme climatic conditions, the unique socio-economic conditions and the stress put on urban planning due to the rapidly growing peri-urban districts.

The main intention of the pilot project was to develop an integrated sanitation system (iSaS) that would be tailored to the local conditions and the situation in Darkhan. However, the possibility to transfer the solution and adapt it to similar circumstances in different countries and climate zones has always been taken into consideration. The system for Darkhan aims to incorporate the ***basic principles of iSaS***, as they have been described in Chapter B.3.

The simplest way to describe the overall system for Darkhan is to present the graphical scheme, which is shown in the following Figure 28. As mentioned above, one basic principle of an integrated system is to make use of the resources contained in waste (liquid and solid) instead of discharging or disposing. The system a.) is based on material-flows, b.) includes collection, transport, treatment and re-use and c.) combines the different technologies in the different urban structures.

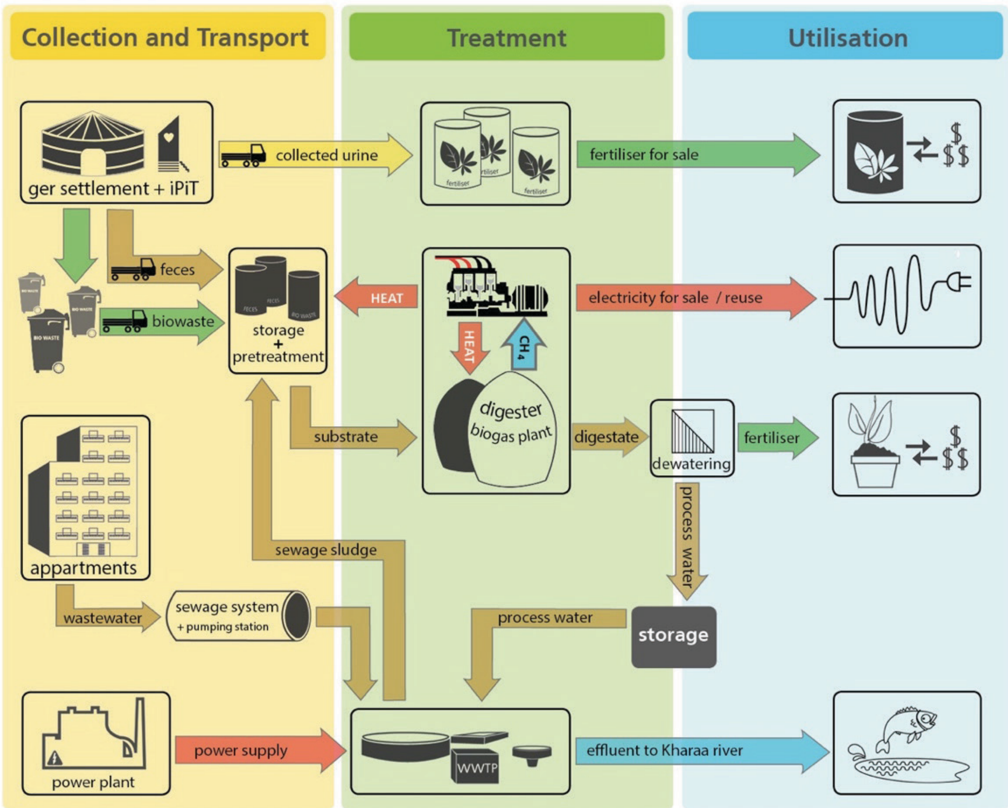


Figure 28: Integrated sanitation system in Darkhan from (Städel et al., 2012) based on an illustration of M. Hartmann

Complementary conditions of the here examined Darkhan case, such as the development of inexpensive technologies, the participatory planning process, the co-ordination with superior communal institutions, and economic assessment, will be described further down.

The systemic approach of iSaS has initially been tested at a pilot scale. As pilot area for the sanitation system in ger areas, the sub-district bag7 has been chosen.

Pilot area bag7

The sub-district bag7 has existed for more than 40 years. The residents have established their lives in this district for a long time. Bag7 is located in the higher areas of Darkhan, which means that flooding or groundwater contamination, are not serious issues. Most of the water kiosks were already connected with the central water line in 2010 and the supply situation is stable. The sanitary situation in other bags in Darkhan near the river Kharaa is certainly more difficult.

The reason for choosing this particular sub-district is simply based on the fact that the governor of bag7, Mr. Tserennadmid Ch., was highly interested and motivated to cooperate, whereas others showed much lower interest in the proposed project. During the project period, it became apparent that this choice was highly rewarding. The following map of Darkhan indicates the different town sub-districts based on (Römer, 2006):

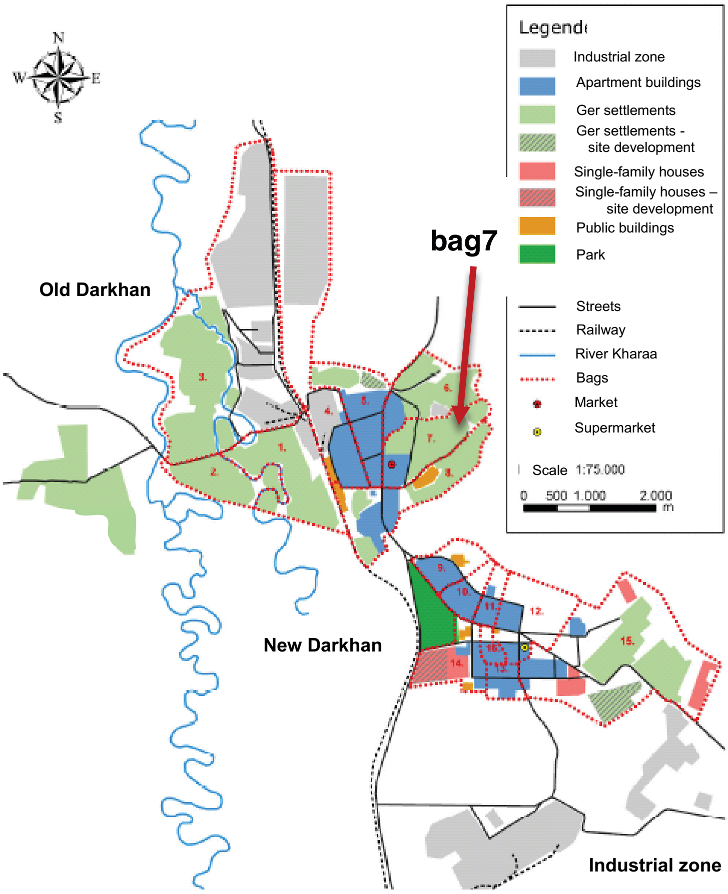


Figure 29: Map of Darkhan with indication of sub-districts or bags based on (Römer, 2006)

Approximately 10 % of the households (HH) in bag7 were included in an initial socio-economic study. The main drinking water sources (99%) are the 11 water kiosks.

According to official information given at a workshop in April 2013 in Darkhan, 6218 citizens live in 1598 families in bag7, but as the population varies over winter and summer time, the mean household size has been determined to be 4.5 persons per HH. The mean income level is in the range of an unskilled worker. However, the real income differs widely, which means, that the social structure is quite diverse. More than ¾ of the residents are owners of their plots of land and houses. The mean expenses for electronic communication per HH is around 3.7 times higher than for supply with drinking water (approx. 6.300 Tugrik per month for water *or 3,70€ in 06.2010*). About half of the residents use the bathrooms of relatives in apartment buildings for personal hygiene while others rely on public bathing houses. Almost all residents use pit latrines in their private compound, sometimes shared with other families on the same plot. **Only ¼ of the children use the latrines.** A comprehensive compilation of all relevant data can be found in (Sigel, 2010).

C.2.2 Material-flows, energy, and technology in the pilot project

C.2.2.1 Material-flows in the pilot project

The project development starts with the consideration of the different material-flows at HH level. It was intended to design the system in a way that enables the separate collection of the different material-flows. Due to certain limitations (see below) not all material-flows were equally assessed and the research focussed on the ones that were prioritised and were regarded as feasible to handle, respectively.

Urine and faeces

The initial focus of the sanitation part of the project was on the separate collection of urine and faeces (resource-oriented sanitation). In workshops on the *prioritisation of the main sanitary problems in ger areas*, this idea has been successfully introduced to residents of bag7 and local experts respectively.

The separate collection of faeces and urine was made possible through the installation of a new urine diversion toilet. Urine and faeces were collected regularly, stored and treated and were intended to get reused in agriculture, as can be seen in Figure 28. The quantification and characterisation of the collected faeces from the pilot project in bag7 have been described in the dissertation of C. Bruski in a comprehensive way (Bruski, 2015). The findings about the separation rate and usage of the dry toilets give important hints for the operation of the system. In this dissertation, complementary research questions have been examined, particularly related to the technical feasibility of co-digestion of faeces form Ger areas with excess sludge of the existing WWTP in a pilot biogas plant. The work is examining an essential part of the iSaS and is therefore complementary to the dissertation at hand.

Greywater

As a result of the low water consumption in ger areas, greywater is reused several times with increasing level of pollution and high COD loads, depending on the activities in the household (e.g. food preparation, animal slaughtering, personal hygiene, washing, cleaning). Strong detergents and chemicals are used in compensation of the low available water quantity. The characterisation of greywater can therefore not be compared with literature values and varies strongly. The current practise is to infiltrate the greywater during the warm periods and simply “store” the greywater frozen on the ground in winter.

One of the results of the initial workshop with bag7 residents in October 2010 was a relatively low prioritisation of greywater (seeconsult GmbH, 2011) as a major problem. At the same time it has been learned, that intensive research activities concerning the treatment or reuse of greywater through greenhouses and other low-cost technologies were carried out by the international NGO *Action contre la Faim* (ACF) in UB (Schüßler, 2011; Uddin, 2015). Because of that and limited project resources, it has been decided to focus on the material-flows of urine and faeces with the option to pick up the problem of greywater treatment at a later time in the project.

Water supply

A similar decision has been made concerning water supply and biodegradable waste. Water supply obviously has high priority for the residents in Bag7. As 9 of the existing 11 water kiosks were already connected to the central DWSS and the remaining 2 were about to get connected as well, the situation was regarded as stable in the given period. The storage of drinking water at the HH level was the main risk of contamination. In order to address this issue, several activities such as awareness raising and hygiene education were carried out at the local school, the hospital, and the local community building organisation (Sigel, 2010).

Biodegradable waste and residues

The solid waste situation was not in the focus of the pilot project. However, the waste-material-flows are an immanent part of iSaS. In order to get some ideas about possibilities for the practical implementation of iSaS at the larger, citywide scale, some preparatory theses have been elaborated. In these theses, technical, organisational as well as economic evaluations are described (Böhme, 2014; Lauckner, 2013; Schuster, 2011).

With regard to iSaS the **biodegradable waste stream is of particular interest**, as well as a combination of transport means and services of solid waste and sanitation services, in order to enhance the ecologic and economic sustainability of the system. Some of the results and further considerations are included in the next chapter.

C.2.2.2 Energy in the pilot project

The process energy (demands and gains) of the treatment process “co-digestion of excess sludge and faeces from ger areas” in the pilot biogas plant has been evaluated. The results are presented in (Bruski, 2015; Londong et al., 2014) and the main findings are displayed in C.3.

An extensive consideration of all energy-flows within the system, such as energy demand of pumping stations, energy for transport of urine, faeces, and solid waste, has not been carried out in the given project period. Energy-flows are considered in the mathematical model for iSaS (see Chapter D).

C.2.2.3 Technology in the pilot project

The main challenges of the practical implementation of the research project was the development of a collection and transport system for urine and faeces, which would fit to the extreme climatic conditions in Mongolia and work in a reliable manner all year round. Toilets have a special role as an interface between the iSaS itself and the users of the system.

The installation of water flush toilets is not feasible, because the connection of Gers and houses to a central water supply and sewerage would be too expensive and water sources are limited.

For the majority of the ger area residents only dry sanitation is an option (Ulrich, 2010). The users want a comfortable and odour-free toilet – other aspects do not play a significant role.

C.2.3 Development of the integrated personal innovative toilet - iPiT®

All components of the system, starting with the toilet as user interface, further on collection (e.g. container, pit), transport, storage, and treatment have to work seamlessly together. Only by a well-designed process chain it is possible to achieve a high level of reliability and acceptance among the users. The design has to follow technical constraints, such as: a.) extreme temperatures, b.) impermeability, c.) handling, d.) transportability, e.) drainability. It equally has to reflect cultural and other local peculiarities throughout all process steps, such as: a.) personal comfort, b.) individuality and privacy, c.) traditional perceptions of human waste, d.) readiness to handle the technology.

Figure 30: Draft design of iPiT® with main parts of user interface: toilet seat and collection bins (based on ACF Mongolia)

For this reason, the toilet has been developed in an interdisciplinary design project at the Bauhaus-Universität Weimar. Through this approach, it was possible to combine the expertise of engineering and product design. The design follows the demand to integrate private toilets into the described overall sanitation system.

The design also had to reflect the residents' demand for privacy. It had to significantly enhance the users' experience of comfort and equally had to ensure smooth operability. One premise for the design was, that **users should not have to deal with** handling of faecal matter or **operation** of the system in any way.

The result of the interdisciplinary work was a urine diversion dry toilet (UDDT), with easy access to the collection bins for an improved kerbside collection (see Figure 30).

A trademark of the toilet has been registered with the name ***integrated personal innovative toilet - iPiT®***. The trademark and the logo were furthermore used to promote resource-oriented sanitation in Mongolia and later also in Cambodia and Germany.

Figure 31: iPiT® logo

The iPiT® was only one – yet a significant - part of the iSaS. **The second major facility of the pilot project was the biogas plant** for the combined digestion of faecal matter and sewage sludge. The biogas plant was located in close proximity to another pilot facility, which was a WWTP based on the SBR principle (Stäudel et al., 2012).

In these two conventional pilot plants, state-of-the-art technology has been used. The research tasks were primarily related to process optimization in extreme climates, local substrates and the local conditions. As several theses and papers are explicitly dealing with these 2 pilot plants and with regard to the used technology, it is at this point referred to the available literature (Bruski, 2015; Karthe et al., 2016).

C.2.3.1 Construction of the iPiT® sanitation system

The construction of the iPiT®'s started in July 2011 with local craftsmen. The initial draft design was adapted in Mongolia, directly during the construction period, in order to meet local skills and locally available material. The NGO ACF from Ulaanbaatar supported the implementation with their local knowledge and expertise. A basic toilet model of the *ACF eco-toilet* was modified and further on copied to meet the needs of the iSaS of Darkhan. The *SEP urine diverting insert, 39x38x21 cm, PP-plastic* from *Berger Biotechnik GmbH, Hamburg*, was the only constructional part, which had to be imported into Mongolia.

Figure 32: a.) Local construction of iPiT® b.) Personal attainment of resident

All other material had to be purchased from the local market. As many of the initially planned materials were not available, this resulted in a different construction of the substructure (vault for collection containers), superstructure (toilet house), and in other certain improvisation measures. Luckily the Mongolian craftsmen have a talent for improvisation, which allowed finalising the construction in time.

Figure 33: a.) Installation of toilet house b.) Finished installation of iPiT® (photos: P.

The support among the local bag7 administration and the residents was generally very high. The idea of creating ownership was an important pre-condition for the project. All participating families were therefore obliged to contribute with personal attainment to the project, either in terms of money or construction work or both. The iPiT®s were installed at 12 Mongolian *khashaas* in bag7, as can be seen in Figure 33.

Figure 34: iPiT® equipped with urinal (not used here) and wash basin

Handover to selected families

Compared to the old latrines, the new toilets marked a big leap forward for the participating families. After handing over of the iPiT®'s to the selected families in September 2011, they have been quickly accepted and personalised, as can be seen in Figure 36.

The experiences of the users, their levels of acceptance, reported problems and damages were examined. If possible, the toilets were optimised within the given timeframe.

C.2.3.2 Acceptance of the iPiT® sanitation system

In order to get a better understanding of the needs of the residents with regard to the suitability of iPiT®, a monitoring program was carried out over a period of two years. It revealed that the acceptance level of the iPiT® and the integrated system itself was remarkably high among population and stakeholders. During the project, period the team received frequent requests to open up the sanitation system to other ger areas of the city. Some of the residents from other parts of the town were even willing to bear all costs for investment into iPiT® and to equally pay for the operational costs.

Figure 35: "Please sit down on the seat, it is necessary for a good separation"

Families have made one remarkable statement regarding the pilot project: **Children stopped the practise of open defecation** immediately after commissioning of the iPiT®. It indicates a sense of comfort and safety, which children need with regard to sanitation. On a personal level this has been one of most important points of success of the pilot project. Another aspect was, that guests and visitors of the participating families had no problems to accept the concept of separate collection of urine and faeces (see Figure 35).

The biogas plant and the iPiTs, received a particularly high level of media attention in Darkhan. Interestingly, the environmental benefits of this system were appealing to the local population. The protection of soil and water, as well as the recycling of faeces and urine were positively mentioned by the residents and contributed to the high public interest. However, intensive capacity development measures for the local stakeholders would still be needed to ensure the self-contained continuation of such a new sanitation system.

A full report of the evaluation of questionnaires of the monitoring programme is given in (C. Grambow, Lamkowsky, & seeconsult GmbH, 2013; Lamkowsky, Saladin, & seeconsult GmbH, 2014). The change of paradigm and the understanding of the diversification of different technological solutions for sanitation, which are combined in one system, do not occur in a sustainable manner in the short period of time of a pilot project.

Figure 36: iPiT® - separation toilet seat: summer and winter version

C.2.3.3 Suitability of iPiT® in summer and winter

From the technological side, it was necessary to test the toilets and the operation of the collection and transport service in summer and in wintertime. The wintertime was the crucial period for the pilot-testing phase. It had to be examined, whether the separation toilet, as well as the collection and storage of faeces would work as intended at long periods of temperatures below -20°C. There are no containers existing, which fulfil all criteria needed for the iPiT sanitation system, which are: **size, form, sealability, impermeability, stackability, portability, drainability, durability and applicability throughout the whole year.**

Figure 37: Cut-through barrel for winter

At the local market in Darkhan, only blue barrels with 60l content (so-called *"wide neck barrel"*) were available and in limited quantities. After production of the iPiT, it was found that the dimensions of the barrels (which all looked the same) varied slightly in width and height. The barrels were obviously not standardised and were not acquired from the same source.

These variations in dimensions of the barrels would have had a negative influence on the structure of the iPiT and major adjustments for each one of them would have been needed. Ultimately this difficulty would be the end of a suitable collection system, which is based on the exchange of barrels. It was decided to purchase barrels with identical dimensions in UB via China.

For the winter period, a set of barrels was cut through and plastic bags were used for the collection of the frozen urine and faeces. This proved to be suitable for the operation of the system in the winter period. In a personal evaluation of the emptying service carried out in February 2012, it was understood that the handling of the frozen urine and faeces in the plastic bags was equally easy to handle as the barrels in summer time. The cold temperatures in winter are certainly a big challenge for the workers.

C.2.4 Monetary-flows and economy in the pilot project

In a conventional system, the flow of money has the same direction as the flow of material. This means, that costs are involved in each step of the process chain. Income generation is usually difficult, which makes wastewater treatment expensive. Users have to pay for the service of collection, treatment and – in many countries – for discharge as well. Screenings and sludge from the treatment process has to be disposed of. This again costs money – directly or later on via environmental costs in case that the discharge takes place in an uncontrolled manner, as is the situation in Darkhan.

By combining the material and monetary-flows of the iSaS in Darkhan, it is possible to identify financial benefits and constraints. Hidden potentials within the system can be discovered. The linking of the technical system (material-flows) with the financial system (monetary-flows) is shown in Figure 38. It can be seen, that the monetary-flows and material-flows are parallel, but the direction of the flow is partly reversed.

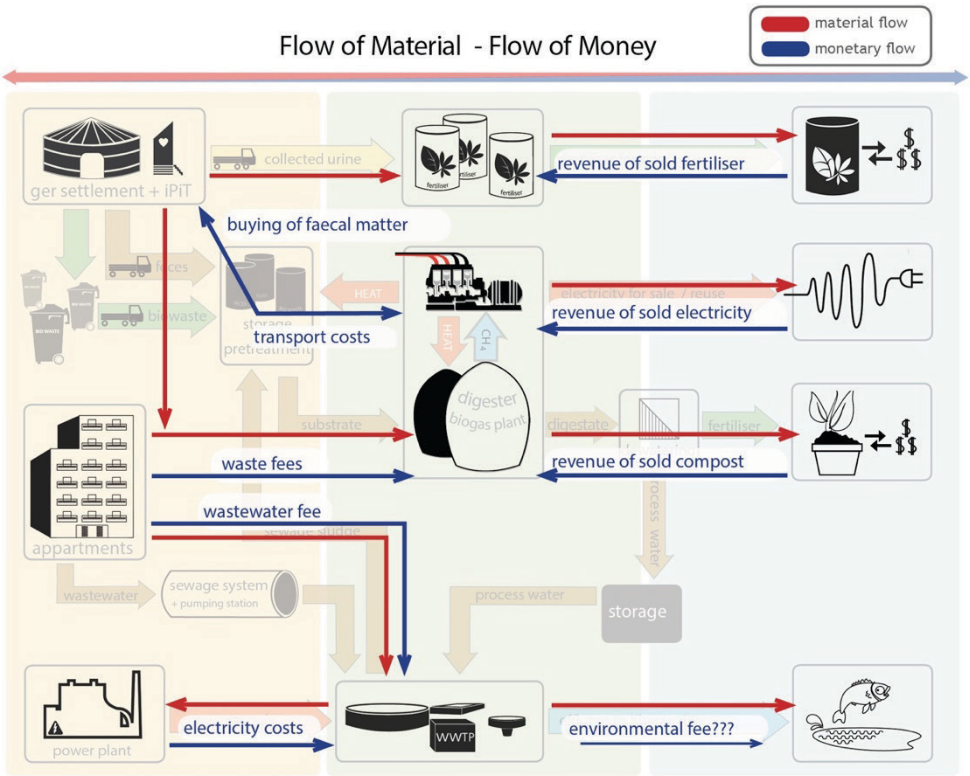


Figure 38: Combined material-flow and monetary-flow

Such an approach would be very new to Darkhan. Subsidies of infrastructure were cut only recently, but fees are still ascertained by the state. As a result, the infrastructure system in Darkhan can in reality not be run economically nor can it be maintained or rebuilt, as reserves are not (yet) built up.

Beyond that, an iSaS is product-driven, meaning that the output of the system is not only safe for a human environment, but would ideally contribute to value added and lower overall costs. **Utilisation of biogas**, the **reduction of external energy** for the WWTP, and selling of **electricity** contributes to the financial affordability of the system. The vending of **quality fertilizer** generates revenue. The revenue created in the biogas plant helps to partly cover the transportation costs for the emptying of the iPiTs and the operation of the system. This allows for keeping the costs of sanitation in ger areas low and avoids barriers for the financially weak users.

Waste, drinking water and wastewater fees are calculated including the revenues. The fee system includes incentives to save water and to deliver biowaste to collection points. The costs for transport, maintenance and general operation of the system are included in the regular fee system of the whole city. For Darkhan, the consequence has to be a significant reorganisation of its outdated structures from socialist times.

C.2.4.1 Operation of the pilot project – chance for future business

Establishing the collection and transport system for the pilot project initially intended to be undertaken in cooperation with the major stakeholders, which are the municipality and the local state-owned company of water supply, sewage and wastewater treatment, USAG. However, USAG rejected to contribute to this part of the pilot project, although it is in their responsibility to actively work on the improvement of the living conditions of the citizens in the ger areas.

With support of the local governor, an entrepreneur of bag7 was motivated to become operator of the system. For the project period is was possible to create some part-time jobs in bag7. This was in line with the initial approach of the iSaS for Darkhan.

Figure 39: The iPiT® and collection and transport by a local service provider

The service provider was paid through the pilot project. Fees were at this stage not collected from the residents. The local service provider exchanged the barrels on a weekly basis and transported them to the treatment facilities on the WWTP. He also maintained the iPiTs and all parts of the transport system.

Figure 40: Container for urine and faeces accessible from roadside

The users were not involved in any way with the system and **experienced a full service.** This enhanced the convenience and comfort and led to a very high level of acceptance among the local population in Darkhan (Sigel, Städel, & Londong, 2014).

The reliability of the service was tested throughout 2 winter periods from 09/2011 to 04/2013. The results of the operation were good and there were no complaints from the users. A complete tour to serve all 12 families in bag7 took about 2 hours including off-loading and emptying of the barrels.

One driver and 2 workers were needed for one tour with one KIA Bongo pick-up truck. The whole tour (all 12 *khashaas*) in bag7 had a length of around 6 km. The trip to the WWTP (where the biogas plant was located) and back to bag7 was around 8 km. Even in winter with icy roads all iPiTs were accessible.

Figure 41: Collection service in winter with modified containers

Future business model for a service provider

If the iSaS would be applied across the whole city, consequently a local service provider could be encouraged to build up a profitable business, which would then be in charge of

i) the maintenance of the iPiTs,
ii) the operation of the treatment facilities and
iii) the marketing and sale of organic fertilizer.

These theoretical valuations were partly considered within the pilot project phase. All expenses for the pilot project, including construction, operation, and salary were covered through the budget of the research project. The major results of the economic comparison of the conventional and the integrated approach towards sanitation at a larger scale, are described in Chapter C.3.

C.2.4.2 Treatment, reuse, and valorisation

In the pilot scale and within the given project period, the potentials of the products were examined in part on a small-scale trial and in part theoretically only. Products obtained from the system are in theory:

- **methane** (biogas), which shall be used to run a gas-powered generator
- **electricity**, which can be sold and / or used for the operation of the WWTP
- **heat**, which shall be used for the digestion process internally. Excess heat can be used to melt frozen organic matter (faeces, biowaste) in winter time
- **fertilizer** (nutrient enriched compost or stabilised sludge), which will be produced from digestate and source separated urine from the iPiTs and
- treated wastewater

The major contributor in the sense of the named products is the biogas plant for the combined digestion of sewage sludge and faeces from ger areas, and potentially biodegradable waste from the Darkhan region (Londong et al., 2014).

Biogas plant

While the co-digestion in Europe corresponds to the state of the art, there are no experiences of running a biogas plant in Mongolia. Two issues especially presented a real challenge:

a) How can the transport system for faeces be connected to a biogas plant?
b) How can a biogas plant be operated in the extreme cold winters of Mongolia?

The pilot biogas plant, which was installed in a 40" sea container, started operation in 2012 on the WWTP in Darkhan. The collected faeces were co-digested with sewage sludge in two biogas digesters. The faeces from ger areas had to be conditioned (removing of extraneous material, comminution, mixing with co-substrate) before feeding them into the biogas plant. In the pilot scale, this had been done manually with equipment in laboratory scale.

Two different modes of operation were tested, which were continuous and discontinuous co-digestion of faeces and excess sludge from the WWTP in a mesophilic anaerobic process. Organic waste as co-substrate has not been tested within the given project period. Based on the characteristics of the utilized substrates a process design was developed. It was anticipated, that the process design would be the basis for the practical implementation of an up-scaled version of the here described iSaS with the proposed technology (Bruski, 2015).

Agriculture as direct beneficiary

After additional treatment steps, the stabilized sludge from the biogas plant can be used as a high-quality soil conditioner in the local agriculture. There, organic fertiliser can be instantly applied in order to mitigate on-going extensive soil degradation processes in the region. Urine is stored and may later on be used as high-value fertilizer.

Mongolia's agricultural sector increasingly has to deal with a depletion of soil nutrients, organic matter and topsoil. Due to expensive fertilizer, increasingly large areas have to be cultivated in order to maintain the yield (Rost et al., 2014). In the reach of Darkhan the cultivated agricultural area covers currently about 60.000 ha. Therefore, there is a large potential value that can be derived from the application of fertilizer, which is produced from human waste (Hofmann, Tuul, & Enkhtuya, 2016).

In the given project period, a few experiments have been carried out with the *Mongolian University of Agriculture* in Darkhan. The experiments intended to demonstrate the nutritional value of fertilizer from the collected urine and faeces from the ger areas. The potential economic value of fertiliser can be estimated on the basis of market prices, as is done in Chapter D. The economic potential should be regarded in the financing of public infrastructure.

Financing model and updated tariff system

The administrative structure in Darkhan is slow in supporting the necessary changes of the underfinanced public services. Due to the political framework, it is difficult to establish cost-effective financing structures. The current tariff structure in Darkhan (price level 2013) is unjust and discriminating, as the residents of the ger areas with lower income pay twice the price for water (≈ 3,000 MNT/m^3) compared to the wealthier residents in the apartment buildings (≈ 1,350 MNT/m^3). At the same time the latter experience a much higher service level, as they have access to tapped water and central wastewater collection.

Some suggestions for improvement have been discussed in the pilot project, such as raising the water tariffs in the apartment areas to a realistic economic value or the initiation of cross-financing of infrastructural development in the ger areas by higher fees in richer urban areas (Gutjahr, 2013). Such measures are by nature subject to political power. The municipal administration in Mongolia has the unfavourable task to raise prices for public services in order to achieve a cost-effective structure. This instance of a need for public discussion leads on to the next chapter communication-flows and capacity development.

C.2.5 Communication-flows, capacity development and structures in the pilot project

Darkhan is the second largest educational centre in Mongolia, which results in a high educational level among the local population. This circumstance facilitates the implementation of new concepts and offers good conditions for the capacity development. The main educational institutions in Darkhan are the Mongolian University of Agricultural (MUA) and the Mongolian University of Science and Technology (MUST), which were also project partners.

C.2.5.1 Capacity development

Capacity development (CD) measures tailored to the local context and involvement of stakeholders were an integral part in the here-described Darkhan case. As far as possible, German and Mongolian students were in involved in the research in order to facilitate the practical side of the academic education. The numerous theses and publications represent some of the results of the CD measures and bilateral cooperation.

More importantly for the development and implementation of the iSaS was the participatory planning process, which aimed to enable the communication between stakeholders in a transparent way. The chosen method for this process was the ***community-led urban environmental sanitation*** approach or **CLUES**. This method has been developed by the *Swiss Federal Institute of Aquatic Science and Technology* (EAWAG) (Lüthi, Morel, Tilley, & Ulrich, 2011). It was adapted, tested, evaluated and further developed within the research project in Darkhan. An increasing interest in the process and growing positive engagement of the stakeholders within the given project period, has been stated as a key achievement in (Sigel et al., 2014).

C.2.5.2 Stakeholder analysis

Already in the year 2009 a first stakeholder analysis has been carried out and the most relevant stakeholders in Darkhan have been identified (Sigel, 2010). With the project's progress, some significant changes of some of the stakeholders took place (e.g. after elections), whereas other stakeholders remained unchanged throughout the project period.

Table 5 shows an overview of the main stakeholders and their role in the process at the end of the project in 2013. In the column "*remarks"* a classification of the attitude of the stakeholders in the pilot project is given. The classification is based on the personal experiences of the author during the cooperation and is certainly subjective.

Table 5: List of stakeholders in Darkhan at end of project in 2013

stakeholder	person	symbol	remark
City administration: Soum governor until 2011	Mr Tsendsuren	TS	was promoted after 2011 to higher position, good contact and supportive
City administration: Soum governor 2012-2014	Mr Azjargal	AZ	very good relation, high interest to improve service of the city
Urban Planning Department Darkhan-Uul aimag	Mr Baast	UPD	reluctant in the beginning, later increasingly interested, slowly changing perception
Major of bag7	Mr Tserenadmid	TA	very supportive since the beginning, very good relationship
USAG		USAG	most challenging partner, difficult to cooperate, closed minded, not innovative
Mongolian University of Agriculture	Mrs Mendsaikhan, Mrs Bazarradnaa	MUA	good relationship, interested, limited resources to support, open for collaboration

stakeholder	person	symbol	remark
Mongolian University of Science and Technology	Mrs Tsevel, Mr Amgalan	MUST	medium relationship, limited resources to support, undistinguished interest
Public Health Department of City Council		PHD	supportive in data provision & socio-economic study, low interest in sanitation
Plant Science Agriculture and Training Institute	Mrs Tuul Dsh	PSARI	good relationship, interested, limited resources to support, open for collaboration
residents of bag7		bag7	very high interest, supportive, demand for access to iPiT sanitation system
residents of other ger areas		bag all	high interest and demand for access to iPiT sanitation system
participating 12 families		12 PF	very high interest, very supportive, very good relationship

With continuing cooperation, it was observed, that the understanding, the support, and trust among most of the stakeholders increased with project progress as well. With growing trust, some sceptical attitudes slowly changed from a restraint point-of-view to a more supportive and sometimes even promoting attitude.

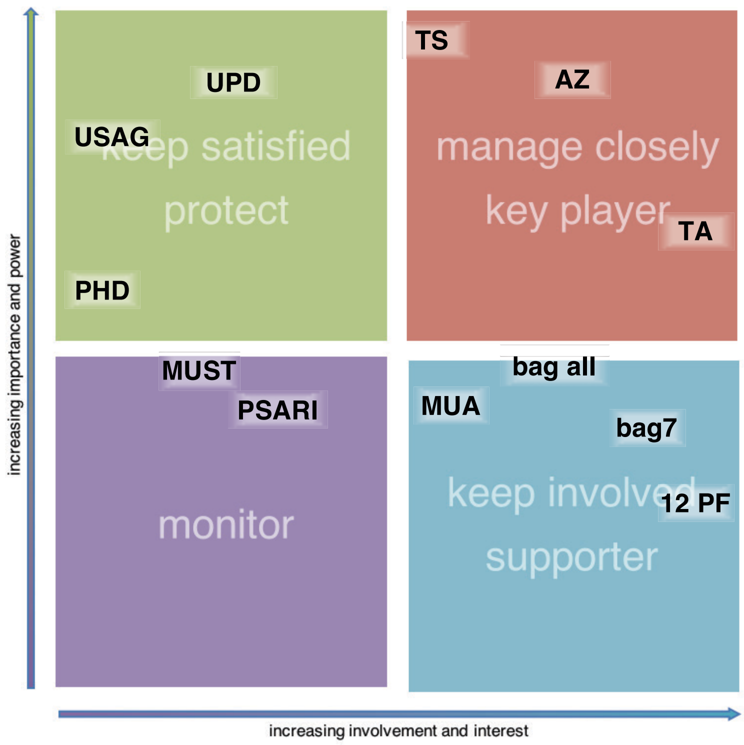


Figure 42: Stakeholder matrix iSaS, Darkhan

In fact, **esteeming and knowledgeable communication is the key to link different groups of people with different attitudes**. This is a precondition to allow for an informed and respected choice across personal or political interests.

The stakeholder matrix in Figure 42 displays an overview of the involved decision-makers and groups. Similarly, to the list of stakeholders above, it is a subjective snapshot from the end of the project in 2013. However, it shows the relations of the stakeholders among each other, as well as their interest and their positive and negative capacity to influence the project results. The stakeholder matrix can be used as a dynamic tool to visualise needs and possibilities / limitations of communication in the project. It equally helps to get a better idea of the particular role of a respective stakeholder in the participatory planning process.

C.2.5.3 Participatory planning as part of project implementation - CLUES

The participatory planning process according to CLUES is organised in 7 planning steps, the maintaining of an enabling environment (e.g. stakeholders, legal framework, regulations), and cross-cutting tasks such as awareness raising (Lüthi, Morel, et al., 2011). This approach has been slightly modified to fit to the local background and the research project (Sigel et al., 2014). The respective process steps are shown in Figure 43.

The role of participatory planning for the implementation of iSaS in Darkhan

The iSaS directly affects the population as end-users and therefrom it is advisable to develop the system in an iterative way with community participation. In order to ensure an effective stakeholder involvement, it was therefore obvious to choose an approach like CLUES, which is so-called *demand-responsive*. The residents and the local administration had a crucial role and it was intended to include their ideas and needs in the design of the system, right from the start.

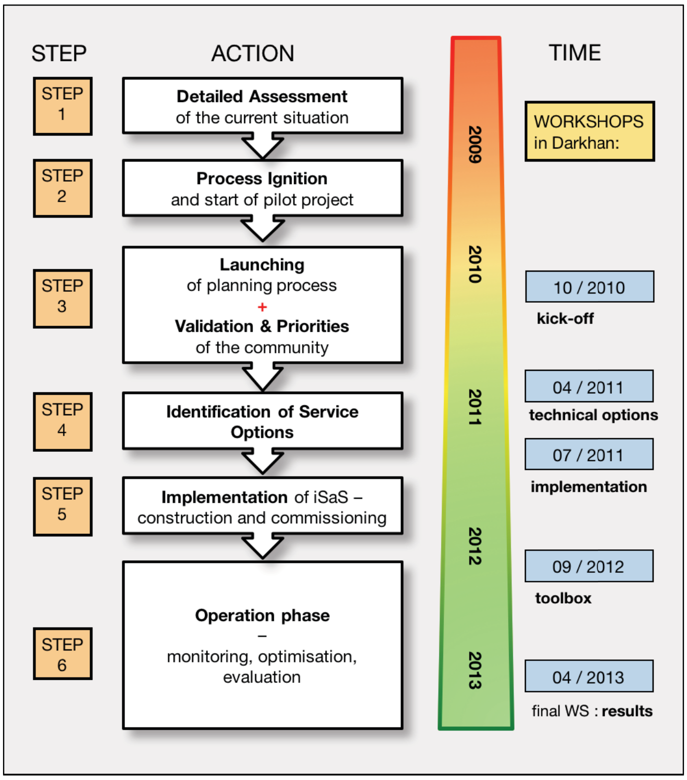


Figure 43: Process steps of participatory planning in the pilot project

Participation on different levels (ministries, city administration, citizens of bag 7) has been organized via several stakeholder workshops in Ulaanbaatar and Darkhan (see Figure 43). In these workshops (10/2010, 04/2011, 07/2011, 09/2012, 04/2013) the experts and residents had the possibility to address their most important problems. Examples are the prioritisation of problems and the choice of technology.

During the workshops it became obvious, that no obstacles were to be expected, neither from the side of the ministerial administration nor from the side of the city or province administration. Initial reservations concerning the proposed sanitation options and wrong perceptions were alleviated in the stakeholder workshops. Problems occurred only with the state-owned company USAG, who is responsible for water supply, sewage and wastewater treatment. The work of USAG only focuses on the apartment areas of Darkhan and rejects responsibilities for infrastructure development in ger areas.

C.2.5.4 Selection of technical options for pilot project

The help of the governor and mayor of the bag7 was very important for the participatory process and later for implementation of the facilities. The participation of the inhabitants of Darkhan's bag7 can be described as a story of success. After the first household survey form 2009, the residents of bag7 were asked to prioritise the need for the improvement of services such as water supply, sanitation, storm water management and solid waste management. The perceptions of the residents of bag7, their attitudes towards, and their demand for improved sanitation services, was equally in the focus of the project launching workshop in 10/2010 and the technical options workshop in 04/2011.

Figure 44 a.) Resident workshop in bag7 - technical options for sanitation
b.) Demonstration of a separation toilet (photo: G. Lamkowsky 2011)

During the 2nd workshop several technological options were presented to the residents of bag7. They were able to ask questions and had the opportunity to comment on advantages and disadvantages of the different technologies. Discussions among the residents helped to provide a common understanding, and recommendations for the further detailed design were given to the German experts. In a final voting on the options it has been the residents themselves, who decided on the type of toilet. They used the opportunity to decide on the proposed solution, which they thought was the most appropriate for their needs and circumstances. During the workshop the need for new sanitation facilities was expressed by most of the residents, but the allocated budget was limited to 12 participating families.

C.2.5.5 Selection of families and monitoring of the pilot project

The selection of the families was done on the level of the city district major, Mr Tserenadmid. His office has been asked to pick the families according to different conditions, which were related to the research questions:

- the families should come from a different social status, meaning a mixture of wealthier and poorer families, which helped to get more diverse socio-economic data.

- the location of the selected families should be well distributed across the city district. In that way, it was possible to gain data on the transport system related to the accessibility of families within the city district bag7.
- the families were obliged to contribute to the new toilet, either in form of money or personal labour. This was particularly important to create a sense of ownership among the families.

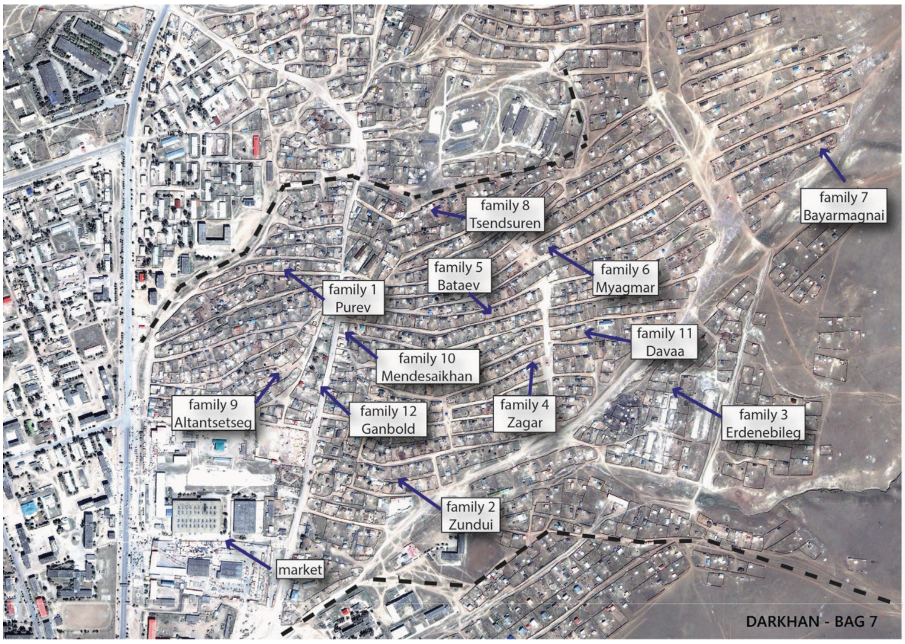


Figure 45: Location of families and iPiT® (own illustration including map data from GoogleEarth)

The spacious allocation of the iPiTs had the effect, that the project became very visible in a larger part of the city. Initial concerns, that this decision would have a negative impact on the operation of the system were not confirmed. It rather helped to promote the project, which resulted in numerous requests of residents to become part of it.

The monitoring program was executed until April 2013. Every two months the local project team visited the participating families. A questionnaire was presented to the families, and personal experiences with the sanitation system as well as inconveniences and other positive or negative experiences were recorded. The monitoring supported the communication with the stakeholders in times of otherwise low project activities. A summary of the results of the participatory planning process in Darkhan can be found in (Sigel et al., 2014).

C.2.5.6 Structures and project extension

After commissioning of the sanitation system in October 2011, it was operated until the end of the project in April 2013. The project mainly relied on the personal connections among the German experts and few Mongolian stakeholders. Contractually the cooperation was supported by a few *Memoranda of Understanding (MoU)* and general agreements between different stakeholders. A local project office with 3 staff members supported the overall research activities and the sanitation project, when needed. Other durable structures were not established in the given project period. The predominant legal and administrative structures in Mongolia and Darkhan were scientifically examined and recommendations have been given on many levels (IWRM, agriculture, infrastructure, etc) (Houdret, Dombrowsky, & Horlemann, 2013; Sigel, 2012).

It was obvious at an early stage of the project, that the local municipal structures would not be capable to make practical use of the scientific results and continue the demonstration facilities, or even implement them in a self-dependent manner at a sustainable scale. Therefore, the local involvement of the research activities was insufficient. Long-term and intensified technical and scientific cooperation would have been needed.

The support for the operation of the iSaS pilot project (including biogas plant) has been extended beyond the project period by several months. Several consultations and negotiations with stakeholders, donors (such as ADB, GIZ), respective ministries and NGOs were held, in hope to find ways to extend the operation of the system beyond the given project period, which was not successful. The pilot project was handed over to the local partners in 2013, which marked the end of the cooperation.

C.3 Results of pilot project – theory and practice of iSaS in Darkhan

Some of the main findings of the pilot project with regard to the theory and practice of iSaS are discussed in this chapter. It starts with a general summary of the main measures for the overall system of Darkhan and continues with the outcomes of the sanitation system for ger areas.

C.3.1 Main measures for urban water management in Darkhan

The whole urban water management situation of Darkhan has been examined, in particular, as the iSaS is meant to be an approach for the entire city and beyond. For Darkhan the main system components were identified and linked with specific measures. These measures have to be carried out in order to get the system functional again (Londong et al., 2014):

1. Repair of wastewater pumping stations.
2. New construction of the central WWTP for 100,000 PE.
3. New construction of industrial wastewater treatment in the industrial zone of Darkhan, as well as uncoupling of industrial wastewater from domestic sewage, as digested sewage sludge shall be used as fertilizer.
4. New construction of an anaerobic digestion plant with co-fermentation options of faeces, biowaste and other industrial organic wastes.
5. New construction of a block heat and power plant (gas engine with generator) at the central WWTP.

6. Installation of special toilets (in this case: iPiT®) at all real estates in the ger areas of Darkhan (approximately 9,000 – 10,000 units).
7. Establishment of a transport system for urine and faeces from the iPiT®.
8. Establishment of a marketing system for organic fertilizer from digestate (nutrient enriched compost) and sanitized urine.
9. Design and implementation of a suitable and accepted fee and financing system.
10. Capacity development for all stakeholders involved on all levels with focus on reliable operation and maintenance of the whole system and its components.

C.3.2 Chain of technology - collection, transport, treatment, reuse

Within the pilot project the maintaining of the high acceptance level revealed itself as the easier part of the research project. The problems, with regard to the technological side are much more challenging, particularly when thinking of the up-scaling of the project and its transferability. This has to do with the out-dated but persisting paradigm of wastewater treatment. The lack of reliable and well-designed technology-chains for dry toilet systems is one of the main hindrances on the way to create global access to sanitation.

Suppliers of sanitation technology solely focus on the conventional wastewater system, arguing, that there would be no market for alternative sanitation systems. As ready technology is not available, it results in improvisational and locally built solutions, which are not efficient, sustainable or transferable. The sanitation system in Darkhan, Mongolia is another example for this circumstance, but some lessons can be learned.

C.3.2.1 Collection – iPiT® as user interface

The iPiT® was constructed with the means, skills, and material, which was locally available. 12 iPiT®'s were produced in the pilot project and they have to be considered as a single-unit production. The monitoring program revealed several issues, which have not been considered in the design phase as some are related to local factors and personal experiences of the users. Detailed findings were summarized in (Riechmann, 2013).

Almost all problems are related to the fact that ready-for-market technology does not exist. Several problems can be named with regard to this instance:

1. The unit cost (≈ 1.25 million MNT or ≈ 710€ in 10/2011, including foundation, materials, tools, transport, and labour) for one iPiT® is too high, considering the type of construction and use of local materials. **Mass production** would solve the problem, and could most likely half the costs involved.
2. A complete **redesign of the superstructure** or toilet house is needed. The design has to deal with the flaws revealed in the monitoring program, such as *cold air draught, lack of dust-*

proof, resistance to weathering, lack of ventilation (solar panel), accessibility for disabled persons and others.

3. The **interior** of the iPiT® has to be redesigned to enhance illumination, comfort and optimised utilisation and cleaning.
4. Optimisation of the **toilet seat** and the separation unit, which is the main interface between the user and the sanitation system: i.) increase of comfort, ii.) improvement of efficiency of the separation unit to avoid misguided urine (Bruski, 2015, pp. 70–75).
5. A complete **redesign of the substructure** or vault is needed. The focus points here are the i.) enhancement of durability, ii.) enhancement of serviceability and iii.) general quality improvements through automated fabrication.

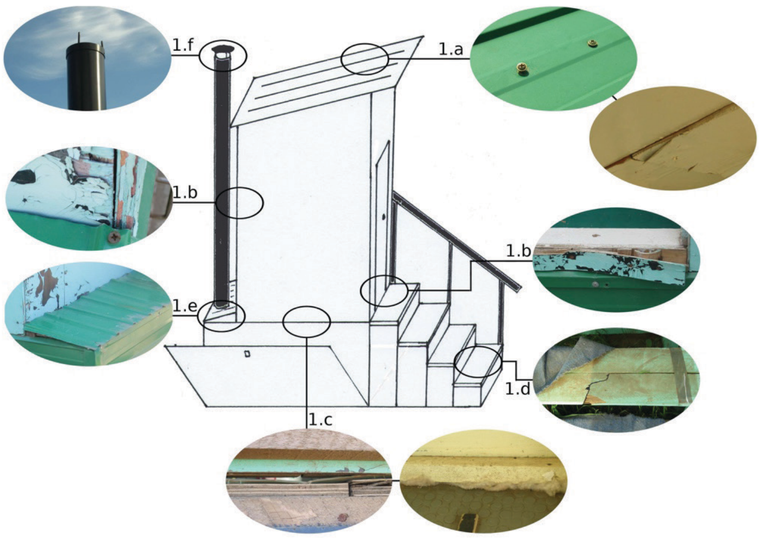


Figure 46: Superstructure of iPiT® - elements for improved redesign (illustration M. Riechmann)

The numbering in Figure 46 and Figure 47 refer to the constructional elements of the iPiT® examined. In total, almost 40 elements have been identified, which need to be optimised and designed properly.

The investigation included elements (visible and non-visible) from all external and internal parts of the superstructure and the substructure.

The identified elements would be the focus points for a diligent and universal redesign of the iPiT®. Such a design is indispensable to receive a marketable product, which can be applied worldwide. In the usual pilot project setting this effort cannot be achieved.

C.3.2.2 Transport, intermediate storage, and accepting station

The redesign of the components of iPiT® has to consider all important elements and contingencies, which can occur during transport, handling, emptying, and cleaning at an accepting station at the treatment plant. For a fully up-scaled project in Darkhan this means, that approximately 12,500 containers have to be handled per week in one optimised technology & process chain.

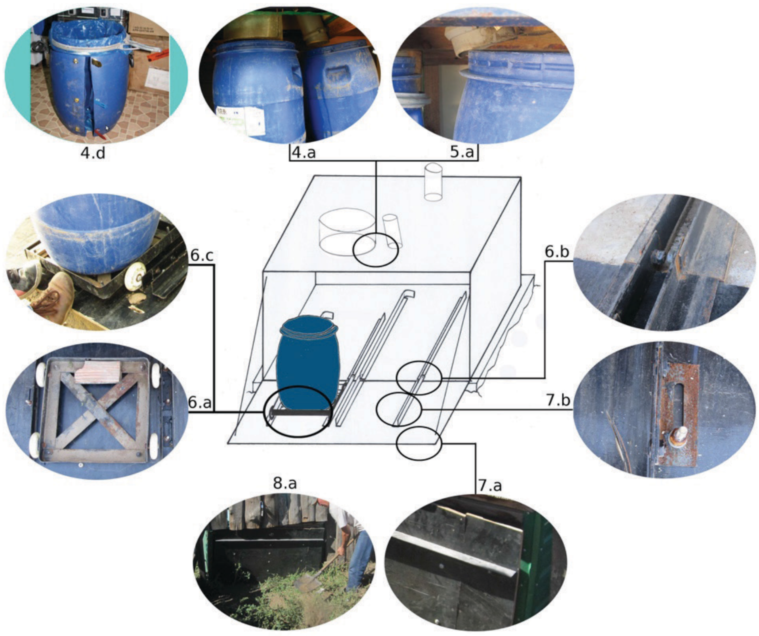


Figure 47: Substructure of iPiT® - elements for improved redesign (illustration M. Riechmann)

Suitable containers, which fulfil all criteria needed for a smooth and economically efficient operation of the iPiT® sanitation system throughout the whole process chain, could not be found.

The containers have to be designed in such a way, that their functionalities are optimised to fit to each conceivable step within the process chain (in location and time).

In each step of the process the containers have to fulfil different functionalities and criteria.

These criteria are:

- size
- form
- sealability
- impermeability
- stackability
- portability
- drainability
- cleanability
- durability
- applicability throughout the whole year

To the knowledge of the author, such containers do not exist worldwide and have to be designed from scratch in order to be made ready-for-market for dry sanitation systems.

C.3.2.3 Treatment in biogas plant and related process design

Faeces collected in the iPiT are frozen during wintertime. As a consequence, they are not directly available as a substrate for the co-digestion. Three options were discussed for a discontinuous operation of a co-digestion using two digesters:

1. When faeces in winter are not available, other feasible organic waste from the Darkhan region is used as a substitute.
2. During summer time co-digestion is carried out in two digesters, which are operating in parallel. In wintertime, these digesters are connected in series.
3. During wintertime, the feeding of one digester is stopped completely. The content remains in the digester while heating is reduced. The operation of this digester will be started again when thawed faeces are available in springtime *(→ dis-continuous co-digestion).*

Complementary, it was also discussed to make faeces available for a *continuous co-digestion* in an all-yearlong operation of the biogas plant. Calculations have shown, that the potentially produced thermal energy, which is used to run the combined heat and power unit, can be used for thawing the frozen faeces in wintertime (Bruski, 2015).

Process design and process technology

In the case of Darkhan with its extreme climatic conditions, the calculations done by Bruski (2015) show, that external thermal energy supply for the anaerobic treatment steps could be completely replaced by the energy produced in the biogas plant. The calculations are based on operational experiences with the pilot plant.

Depending on the process steering, the *mono-digestion* of sewage sludge starts to show a continuous positive thermal balance with 15,000 PE (apartment blocks connected to WWTP). Including the faeces from ger areas (and in dependency of the ratio PE in apartment blocks / PE in ger areas) the *dis-continuous co-digestion* shows a continuous positive thermal balance with 35,000 PE from apartment blocks and an undetermined percentage of PE from the ger areas in wintertime.

Interestingly, in the continuous mode of operation with thawing of faeces in wintertime (*continuous co-digestion*), the thermal balance of the process starts to be positive with 20,000 PE from apartment blocks and an undetermined percentage of PE from ger areas. The reason is the optimised use of digestion volume, which results in smaller treatment facilities. In summertime the thermal balance is always positive (Bruski, 2015, pp. 108–116).

The results above show, that the *process design* has been examined well in the pilot project. However, the ***process technology*** for an up-scaled version of the iSaS for Darkhan, still leaves some open questions:

The **handling of faeces** is difficult due to its consistency and its pathogenic content. For an up-scaled project there are feasible technical devices existing: Automatic **container cleaning systems**, which are commonly used in solid waste treatment facilities, have to be installed. Such cleaning machines are cost-effective and one unit can clean up to 100 containers per hour. This results in approximately 125 working hours to clean the containers of the iPiT® system of Darkhan.

The container emptying and cleaning system would be part of the accepting and **conditioning station** of the treatment facility, which is a crucial part of technology in the process chain. While the planning is theoretically a simple task of process engineering, it has to be stated, that such a facility for handling of large numbers of containers from dry toilets has just never been constructed and operated before.

C.3.2.4 Reuse - fertiliser production for agriculture and forestry

The agriculture sector in Mongolia is confronted with increasing loss of topsoil and a significant decrease of organic matter followed by a loss of nutrients. Soils are suffering of low water holding capacity and low fertility. For instance, as stated in (Hofmann et al., 2016, p. 489), the annual loss of N for the Darkhan region is estimated to -24 kg ha^{-1} a^{-1} with an 0.0 application rate of fertiliser. The P balance is likewise negative in the area with -4.3 kg ha^{-1} a^{-1}. Ever larger areas have to be cultivated in order to maintain the yield, which shows the potential for value added reuse of organic fertilizer (Rost & Londong, 2013).

On the contrary, the Mongolian development plan includes the goal to be independent from food imports (Khuldorj, Bum-Ayush, Dagva, Myagmar, & Shombodon, 2012, pp. 13–25). The intensification of agricultural production (in particular the declared production of wheat!) is currently happening, which is followed by an increasing demand for fertilizer. However, a market for imported, chemical fertilizer is not well established in Mongolia, and it is also not affordable for the majority of farmers.

The agricultural area within the river basin covers around 80,000 to 90,000 ha (fallow land included). The cultivated area covers 60,000 ha of which 6,000 ha are irrigated. Within a range of less than 20 km around Darkhan city, an estimated 21,700 ha of farmland can be found (see Figure 48). The farmland is well accessible in most parts with paved roads.

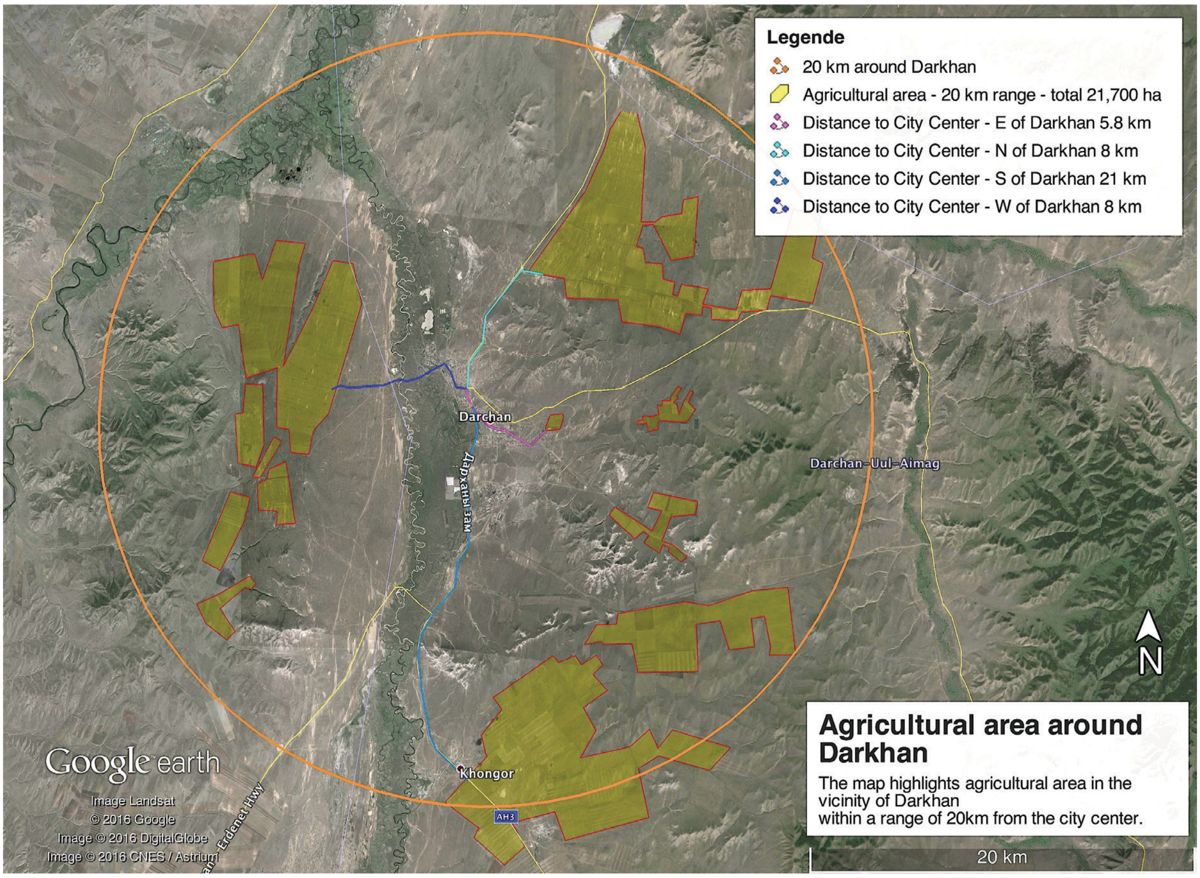


Figure 48: Farmland in the vicinity of Darkhan

Scenario:

The goal is to **double the annual amount of wheat yield** in the vicinity of Darkhan to 3.5 Mg ha^{-1}. The following estimation indicates the reuse potential of nutrients from the iSaS of Darkhan. In this example only **urine from ger areas** is considered:

60,000 residents from ger areas produce roughly 188 Mg N a^{-1} in form of a liquid fertiliser. Assuming an application rate of 65 kg N ha^{-1} this would result in roughly 2,900 ha of farmland that can be fertilised with the urine from ger areas alone. This is more than 13% of the farmland in the 20-km range around Darkhan, or more than ¼ in the closer areas.

For comparison: In Germany, the average yield (8-9 Mg ha^{-1}) of wheat is roughly 6 times the yield of Mongolia in the year 2012 (1.5 Mg ha^{-1}). Removal rates of nutrients in kg ha^{-1} can then be estimated to 150-200 N, 30 P, 32 K, and 13.5 S. Economic optimal application rates of N (strongly depending on the location !) easily range from 135 to 230 kg N ha^{-1} in Germany according to (YARA GmbH & Co. KG, 2012).

It has to be stated that calculating fertilising rates, yields and soil fertility is subject to a lot of uncertainties. It is strongly depending on the location, the regarded fertiliser and other factors. It requires experience and local knowledge. However, the here-described potential is not negligible. Not only can the nutrient dis-balance be compensated; also, production methods can be more efficient, as a higher yield can, for instance, require less area of farmland to be cultivated.

It is obvious to think that the concept of nutrient reuse represents a promising cost-effective solution, and that it could be easily implemented in the short-term. Still reasonable effort has to be undertaken in order to set up a local market for organic fertiliser, as well as to build up storage capacities and to adapt the means for spreading. At the same time the organisational structures need to be built up for the farmers and the municipal service.

C.3.3 Economic feasibility and socio-economic aspects

C.3.3.1 Dynamic cost comparison of different toilets and transport systems

In order to examine the economic efficiency of the iPiT® sanitation system in Bag 7 (Darkhan), a cost comparison has been undertaken using the guidelines (*“KVR-Leitlinien”*) for the dynamic cost comparison method (DWA, 2012).

Complementary to the iPiT® sanitation system, four other concepts for a dry sanitation system have been drafted and evaluated. The different concepts were based on UDDTs in combination with different technologies for collection (sealed concrete pits, underground plastic storage tanks, IBC container) and transport means (pick-up truck, pumping truck, tractor with trailer). The cost estimate has been used in the dynamic cost comparison, included investment, operation, maintenance, education, CD, re-invest, as well as capital costs.

From the cost estimate, project cost present values have been calculated and examined over an investigation period of 40 years. The development of the cost present values of selected sanitation concepts is displayed in Figure 49. It shows the basic calculation with a real interest rate of 3 % p.a. and an estimated number of 1,000 khashaas in bag7 (rounded). The sensitivity analysis with varied interest rates and inflation rates was done with similar outcome.

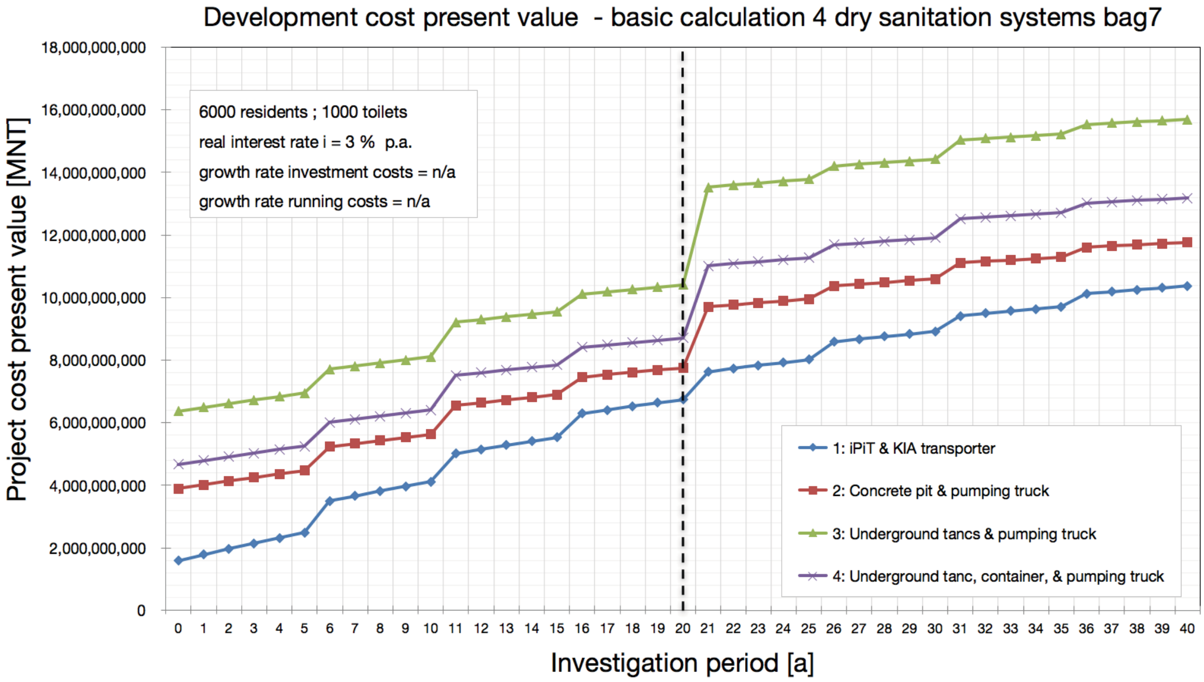


Figure 49: Result of basic dynamic cost comparison (based on Schuster, 2012)

The results show that the iPiT® sanitation system is most cost-effective among all the considered sanitation concepts and over different investigation periods (Schuster, 2012). It has to be emphasized, that **the collection and transport of domestic solid waste has been included** in all the examined sanitation concepts.

C.3.3.2 Comparison of conventional wastewater system with iPiT® sanitation system

In a further step, a preliminary planning for a conventional sewage system for Bag 7 was undertaken (see Figure 50). A **set of tender documents** with project description, preliminary drawings, specifications, standards and detailed BoQ was prepared.

Several construction companies in Mongolia were invited to provide bids in a tender process in February and March 2013. The companies were informed that the tender process would not lead to an assignment in order to avoid price dumping. The intention behind the tender process was to gain realistic values of construction costs for the theoretical sewage system.

Four companies (USAG, Monkh-od-Tsatsral, MUST / Prof. Amgalan, and Komport Impeks / BT Engineers) handed in a priced offer. The tender process revealed, that the Mongolian construction companies were not yet competitive regarding the conditions of the bidding process, yet three of the offers were in a form, that could be evaluated.

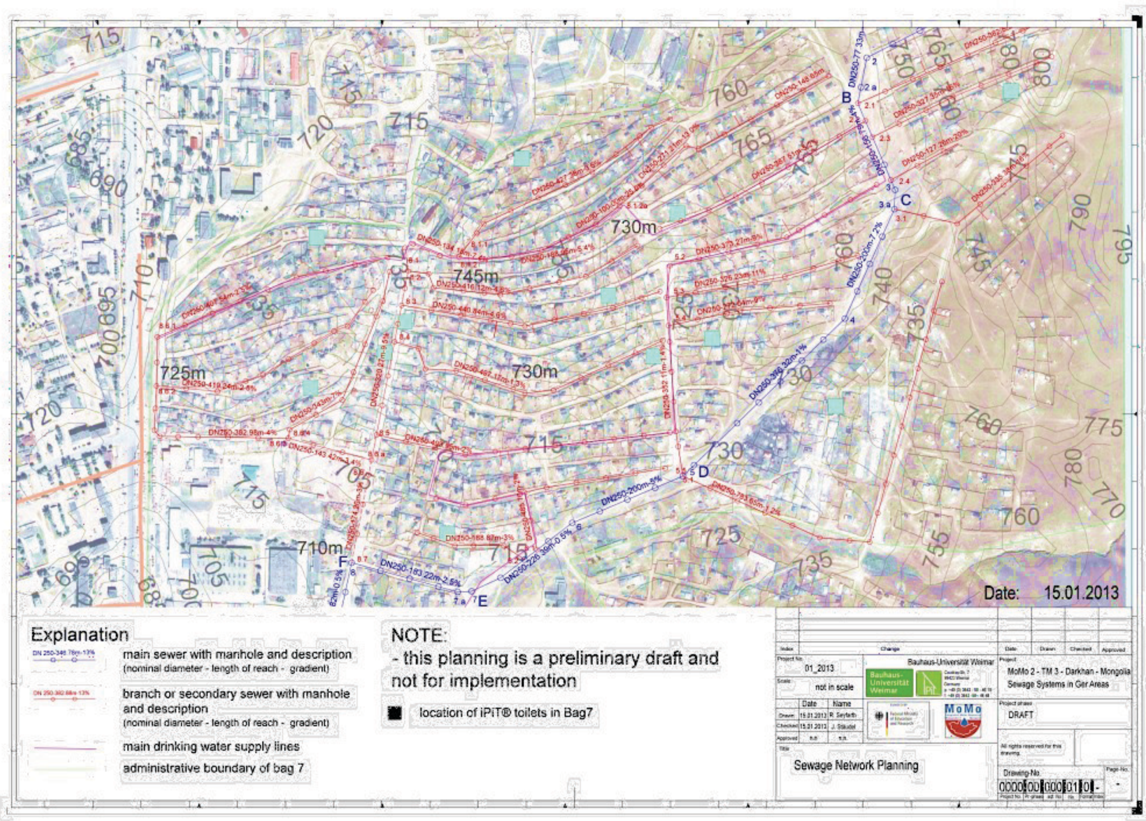


Figure 50: Preliminary sewage network bag 7, Darkhan

The three offers underwent an extensive plausibility check in order to receive a comparative analysis of the bid items. The average price of the three suitable offers for the investment cost is roughly 14.3 billion MNT (≈ 8 million € in 03/2013).

The evaluation of the tender documents showed, that the **investment costs** alone **for** a conventional **sewage system** for bag 7 would be **at least 10 times higher than** the investment costs for **the iPiT sanitation** system. This consideration does not include the potential to significant cost reduction through mass production of iPiT®.

With the help of the dynamic cost comparison model it became apparent that the **overall costs for the iPiT sanitation system** (including waste management!) for bag 7 including its complete operation **over 40 years are lower than the investment costs of a conventional sewage system alone**. Cost for separate heated bathrooms (conventional sewage system) in the houses or yurts are not even considered.

C.3.3.3 *Willingness-to-pay and financing models*

A survey in bag7 showed that the residents would be willing to contribute between 2€ and 4€ per month for this service. For instance, according to (Badran, Jamrah, & Gaese, 2010), poor families in Egypt could contribute around 2-5% of their annual income to water and sanitation infrastructure (Badran et al., 2010), which is in a range of the international recognised 3% ratio (Gawel, Sigel, & Bretschneider, 2011). With regard to the average income of families in ger areas in Darkhan this would raise the **theoretical** monthly **expenses** to **more than 6€** (including drinking water). Different alternative financing models have been examined for bag7.

Such a model should though integrate the (probably existing) financing models of a waste management system, as well as existing wastewater treatment and water supply systems respectively. A thorough evaluation of the economics was not part of the research but is an obligation for the future developments in Darkhan. However, the selection of an applicable future model is equally based on political decisions. The need for adapting the administrative structures can be seen in the problematic example of USAG.

C.3.3.4 *Capacity development and political influence*

The water supply system is a relic of the socialist times with massively subsidised water prices. The subsidies are no longer paid by the state to the local water supplier, but the water fees could not be raised accordingly, which results in an extreme investment gap. The system is close to a total failure because spare parts for the old equipment are not available anymore. To take over responsibility for an integrated system, as described above, is far out of the focus of USAG, which is still working in former socialist structures and attitudes. New structures and responsibilities have to be found and a **massive rethinking has to be initiated**. Another problem of the local water supplier is lacking operational knowledge to build and operate a modern WWTP with anaerobic sludge treatment and co-fermentation.

That is why CD for the communal operator is very necessary. In order to establish a state-of-the-art scientific monitoring as well as a sustainable operation of the system, it is recommended to include the local universities in CD activities. CD is also indispensable in terms of establishing a fee system, which will allow the financing of the integrated system.

C.3.4 Group solutions, decentralised systems, and flexibility in ger areas

According to the municipality of Darkhan, ger areas are expected to remain unchanged for at least another 20 to 30 years before they might be replaced by modern urban housing structures. The housing density in ger areas is very low and sewers have to be laid in a depth of 4-5 m in order to be frost-protected. Furthermore, each house or ger would need a **separate heated toilet room**, which most of the people could not afford to build.

Therefore, with regard to the results of the economic comparison of different sanitation systems, it has to be stated, that all pipeline-bound sewage systems, such as small-scale wastewater works, are highly uneconomical, irrespective if the concepts are centralised or decentralised.

As ger areas will vanish with modern urban housing, other adapted infrastructure solutions will be necessary in the future. Investments into sewers in ger areas would then be lost with the change of urban structures. The iPiT® sanitation system can easily be removed if not needed anymore.

C.3.5 Critical summary of iSaS framework conditions

The following Table 6 provides a summary of the framework conditions of the iSaS in Darkhan. It is based on the criteria and indicators, which have been described in Chapter B.3, Table 2.

The general (yet critical) valuation is based on the personal experiences, which were gathered in the given project period in Mongolia.

Table 6: General conditions for the development and implementation of iSaS in Darkhan – evaluation of criteria and indicators

aspect	criteria	indicator	requirement / objective ("*iSaS has to be...*")	general condition	remarks / evaluation of the realisation of the iSaS criteria and indicator in Darkhan
technology	technical standards	level of technological development	fit to the general state of development	🟢 🟢	technical design fits to local state of development
		applicability and sufficiency of technical standards	applied or improved	⚪ 🟢	the system is not contradicting local standards
	service level water, waste, energy	connection rate	developed towards 100%	🟡 🟡	less than 50% are connected to a sanitation system, but would be improved through iSaS
		service reliability / operation	evaluated & optimised	⚪ 🟡	service reliability is low and needs to be improved
		maintenance level	evaluated & optimised	🔴 ⚪	maintenance is a big issue and needs to be improved
	state of existing infrastructure	operational reliability	evaluated	🔴 🟡	existing infrastructure is deteriorating and functions partially
		remaining value	evaluated	🔴 ⚪	very low, as most of the existing infrastructure is at the end of useful service life
	reuse options	value of fertiliser	evaluated as reuse depends on market accessibility	🔴 🟡	fertiliser is hardly used, as it is too expensive. market options need to be developed
		fertilizer market accessibility	evaluated as reuse depends on market accessibility	🟡 🟡	accessibility of farmers need to be improved and market needs to be developed
ecology	climatic conditions	temperature	assessed, as it provides basic data for system design	⚪ 🟢	technical design fits to local conditions
		water availability, hydrology	adapted to local conditions	⚪ 🟢	technical design fits to local conditions
	natural resources	soil	assessed, as it influences reuse possibility	🟡 🟡	poor agricultural soil in the area, but reuse potential needs to be opened up through capacity development measures
		construction material	considered and influences design	⚪ 🟢	most of construction material can be imported, local production methods can be encouraged
	topography	elevation, slope	considered and influences design	🟢 🟢	technical design fits to local conditions
settlement structure	number of users	population density	sufficient for economic operation	⚪ 🟢	number of users sufficient for economic operation, but not at pilot scale
	accessibility (transport ways)	spatial development / density	needs to be suitable for technological design options	🟢 🟢	sanitation system is designed to fit to the local urban structures
		existing infrastructure	must be considered & included	🟢 🟢	sanitation system is designed to fit to the local existing infrastructure
	legal status	formality of settlement	formal settlement needed	🟢 🟢	criteria is fulfilled
economy	economic system	free or restricted market	considered	🟡 🟢	free market developing, but security of investment can be problematic due to socialist past
		entrepreneurship ⟷ state ownership	considered	🟡 🟡	entrepreneurship is not distinctive at the time, state owned companies suffer from socialist past
	economic resilience	employment status	considered	🟡 🟡	high unemployment rate, economic resilience towards global market fluctuation is low at the time
	affordability	economic growth	stable	🟡 🟢	economic growth is high, but has strong fluctuations in recent years, gross national income per capita is annually increasing
		willingness-to-pay / wealth / sufficient income level	at minimum level; not suitable if population too poor	🟡 🟢	affordability varies among the residents, observations in the pilot project show willingness-to-pay with rising awareness

aspect	criteria	indicator	requirement / objective ("*iSaS has to be...*")	general condition	remarks / evaluation of the realisation of the iSaS criteria and indicator in Darkhan
economy	economic benefits	costs for communal services water, waste etc.	evaluated and optimised	🟡 🟡	cost structure is divided among different services and not consistent, needs to be harmonised
		income generation	ideally improved with iSaS	⚪ 🟢	possible, but not at pilot scale
		creation of jobs	ideally improved with iSaS	⚪ 🟢	possible, but not at pilot scale
	finance	financial capacity of operator / institution / municipality	considered and build up capacity	🟡 🟡	financial capacity is low, state-owned company stuck in socialist mind-set
		business plan	considered and build up capacity of long-term operation	🔴 ⚪	state-owned company stuck in socialist mind-set, business plan for new service operator needs to be developed
		liquidity / credits	build up capacity for long-term operation	🟡 🟡	state-owned company needs to build up reserves and investment plan, liquidity of new service operator needs to be developed
socio-culture	religion	special rules	considered	🟢 🟢	criteria is fulfilled
	culture	faecophilic ⟷ faecophob / washer ⟷ wiper / squatter ⟷ sitter	considered	🟢 🟢	criteria is fulfilled
	education	literacy / educational level	considered	⚪ 🟢	high level of literacy in project area, but awareness raising and public education necessary for implementation of sanitation system
	gender	traditional male and female roles	considered	🟢 🟢	women carry responsible and respected positions in Mongolian society
	physical and mental capacity of population	public health status	known, should be improved	🟡 🟢	alcoholism is a severe problem in Mongolia, although the average consumption is much lower compared to Germany, water-related diseases are prevalent, hygiene will be improved through iSaS
	societal stability	security	at a minimum level, stability is required	🟢 🟢	social tensions are prevalent in poor urban areas, but generally very stable country
		peace	at a minimum level, peace is pre-condition	🟢 🟢	long history of peace since WWII
institutions	state structure	political situation	stable	⚪ 🟢	frequent recent changes in Mongolia, mostly peaceful
		government	included	🟢 🟢	frequent recent changes in Mongolia, mostly peaceful
	legal framework	national, regional, local legislation	considered / respected / improved	🟡 🟡	under development, need for harmonisation
		environmental law	considered / respected / improved	🟡 🟡	under development, need for harmonisation regarding sanitation, environmental standards & decentralised responsibilities
	legal system	legal certainty	provided, as it is important for economic operation	🟡 🟢	under development, gaps with regard to sanitation systems & decentralised responsibilities
		functioning jurisdiction	provided, as it is important for economic operation	🟡 🟢	under development
		level of corruption	as low as possible, high level is main disqualifying indicator	🟡 🟡	Mongolia has a medium corruption index 39, rank 72 from 167 in 2015, less common on local levels
	institutional capacity	reliable administration and management capacity	provided, as it is important for economic operation	🟡 🟡	capacity development during project implementation needed, personal connections with decision-makers important
		level of centralisation / capacity of local decision-making	considered and strengthened, as local decision-making capacity is necessary	🔴 ⚪	high level of centralisation can block local developments

unfavourable conditions 🔴 🔴   🔴 ⚪   🔴 🟡   ⚪ 🟡   🟡 🟡   🟡 ⚪   🟡 🟢   ⚪ 🟢   🟢 🟢 ***ideal*** conditions

C.4 Conclusion

Mongolia is a transition country, trying to overcome the heritage of many decades of socialist rule and state-directed economy. The country is struggling with the rapid change of political and economic values, weak economy, and deteriorating as well as a partly absent infrastructure. In particular, the sanitary situation in the urban *Ger* (Mongolian for *yurt*) *areas* remains very difficult for the citizens. ger areas are rapidly growing peri-urban districts, which mainly consist of yurts or small, detached houses. Urban planning and infrastructure development remains a big challenge in these areas due to the extreme climate in Mongolia, the unique socio-economic conditions and a lack of affordable and fitting technology.

The pilot project *"sanitation in ger areas in Darkhan"* examined the suitability of *integrated sanitation* in the city of Darkhan, Northern Mongolia. The main goal was the connection between the existing conventional wastewater system with a new dry sanitation system based on the no-mix toilet iPiT®. Material-flows were ideally guided in a closed loop. Monetary-flows should be partly reversed in the system in order to achieve higher cost-effectiveness. The system focused on resource management and was product-driven.

The iSaS of Darkhan examined the three levels of material-flows, monetary-flows, and communication-flows in a pilot scale. The system was developed in a participatory planning process, which involved all-important stakeholders. Capacity development measures, such as workshops and academic education, enhanced the understanding of the project goals and improved the communication between all stakeholders. This combined planning approach led to a high level of acceptance among most of the involved groups.

12 iPiT®'s *(integrated personal innovative toilet*) were installed in one of the ger areas in Darkhan and tested over a period of 2 years. A service provider was in charge of transport, operation, and maintenance of the iPiT® sanitation system. The users experienced a rise in comfort and a reliable full service. By monitoring the experiences of the residents, it was possible to improve the system continuously. The main contribution in terms of recycling and sustainability was the biogas plant for anaerobic co-digestion of sludge from the WWTP and faeces from the iPiTs.

Lessons learned

Generally, the Darkhan case proves the feasibility and reliability of iSaS as a meaningful approach for urban infrastructure development. Some significant "*lessons learned"* can be derived from the results of the iSaS for Darkhan.

1. Material-flows and technology - need for detailed technical design

The implemented technology and the operation of the sanitation system demonstrated the viability as a solution for dry sanitation at an urban scale. However, the technological design of the system components and the patency of the process chain are not yet sufficiently elaborated for a reliable citywide implementation of the iSaS.

The lack of reliable and well-designed technology-chains for dry toilet systems is one of the main hindrances on the way to create global access to sanitation. Among the producers of sanitation technology, the focus is almost solely on the conventional wastewater system, and the level of innovation on this sector is too low. Typically, it is argued that there would be no market for alternative sanitation solutions.

As ready technology is not available, this results in improvisational and locally built solutions, which are usually neither efficient, nor sustainable or transferable. This problem can be solved by reasonably investing into a well-designed technology chain from toilet, to transport facilities, to accepting station, to treatment, and to reutilisation, with the goal to produce a worldwide marketable product.

2. Monetary-flow and economic feasibility

The economic sustainability of a system is closely linked to a functional technology chain. For the Darkhan case it was confirmed, that the iSaS is far more economical than any conventional wastewater system. Most likely this is also the case for all other cities in Mongolia.

However, some risks have to be mentioned here:

a.) each economic consideration is case-dependent. As iSaS are more complex and not yet established, they also demand an open-minded attitude and courageous approach to go beyond conventional methods of economics calculation. For instance, this can be shorter observation periods or inclusion of cost recovery from reuse of material-flows and others. Economists need to be encouraged and educated to do so.

b.) in public infrastructure development, financial decisions usually go hand-in-hand with political decisions. In the Darkhan case this would involve a significant rethinking of the current cost structures or would mostly likely require a complete reorganisation of the municipal services, including the need for adapted political guidance.

3. Communication-flow and administrative structures

One observation from the Darkhan case is, that esteeming and knowledgeable communication is a key activity to link different groups of people with different attitudes. The participatory planning process helped to increase transparency, understanding and a sense of ownership. Within the pilot project the maintaining of a high acceptance level revealed itself as the easier part of the project.

However, it was obvious at an early stage of the project, that the local municipal structures would not be capable to make practical use of the scientific results and continue to operate the demonstration facilities or even implement them in a self-dependent manner at a larger scale.

Further on not all stakeholders were willing to contribute to the project, although it would have been in their responsibility to actively work on the improvement of the living conditions in ger areas.

This is an indicator for an out-dated organisational structure, which needs to be replaced. Economic incentives coming from the operation of iSaS can be a trigger for the formation of a new service provider and new administrative structures. In general, substantial capacity development measures have to go with the development of iSaS.

D Mathematical model for iSaS based on material, energy & monetary-flows

In this chapter, the development of a mathematical model, which is based on the principles of iSaS is described. The Darkhan case is used as an example to examine the potential of such a model for scientific purposes as well as its possible practicality in a planning process.

Aim of mathematical model

The model aims to describe the impact of a sanitation system on the environment, to discover potentials for the value-added reuse of nutrients (and other content of the material-flows) as well as to demonstrate the respective economic consequences. The ability to quantify resources, energy and costs in a combined way, shall be a basic functionality. Further on it shall support decision-making and shall help to define the minimum useful scale of an iSaS.

The model shall visualise the material, energy, and monetary-flows and shall help to simulate the impacts of variable parameters, such as flexible energy prices, changing demography, costs and more. Variations of the input parameters and system layout respectively would allow for the comparison of different scenarios. Eventually this supports the planning and detailed design.

The following questions help to describe the intended basic functionality of the model. Some of the questions will later influence the comparison of different scenarios (see chapter D.4.3):

- How much COD load has the wastewater treatment plant to manage?
- How much NPK can be recovered after the treatment process?
- Where are the main sources of pollution in the system?
- What are the costs of transport for urine and faeces from the iPiT® system?
- How do operational costs of a proposed iSaS compare to a conventional system?
- What are the annual costs of the proposed iSaS?
- How does the transport distance of products from iSaS affect the systems' cost effectiveness?
- Which equivalent value of NPK from urine and faeces can be recovered compared to locally available fertiliser?
- What effects have transitional steps on the overall system (e.g. through urine diversion in apartment blocks through installation of male urinals)?

D.1 Background of modelling and simulation for decision support

Mathematical models (static or dynamic) are often used as tools to describe and examine water supply systems, urban drainage systems, WTTPs, and single processes of the aforementioned. They have to be considered as state-of-the-art tools in engineering science and planning. Despite the pure scientific use of mathematical models, they are often used as tools for decision support in planning and design of wastewater systems.

D.1.1 Decision support for alternative sanitation systems - state of science

In recent years, model-based decision support systems (DSS) have also been developed for alternative sanitation systems. A brief overview of some relevant publications is given here.

The dissertation of A. v. d. Vleuten-Balkema "*Sustainable wastewater treatment: developing a methodology and selecting promising systems"* assesses the sustainability of WWT systems by combining tools such as life cycle assessment (LCA), cost-benefit analysis and social inventories. A model has been developed in Matlab®/Simulink®, which is based on a combination of mass balance, energy, cost analysis, and social indicators. These are normalised and weighed in order to deviate sustainability indicators. The model is very extensive, but also too complex to apply in planning tasks in developing countries (van der Vleuten-Balkema, 2003).

The dissertation of F. Meinzinger "*Resource Efficiency of Urban Sanitation Systems: a Comparative Assessment Using Material and Energy Flow Analysis"* compares two different case studies of urban sanitation systems in Hamburg, Germany and Arba Minch, Ethiopia. In this work cost, energy, and material-flow analysis have been combined to assess the resource efficiency of the two different systems. The assessment has been undertaken by modelling the case examples in the software SIMBOX. The focus of the work lies mainly on technological aspects and costs, and does not describe the development and implementation of the different systems in practise (Meinzinger, 2010).

The dissertations of S. Fach "*Bewertung der Abwasserbehandlung in Entwicklungs- und Schwellenländern"* and Suwartanti Nayono *"Development of a Sustainability-based Sanitation Planning Tool (SusTA) for Developing Countries"* have been developed on the basis of the same case study in Gunung Kidul, Indonesia. The works adapt and apply conventional DSS, such as use-value analysis, MFA and LCA to the specific framework in Indonesia with focus on sustainability indicators and sustainability-based planning in developing countries (Fach, 2013; Nayono, 2014).

LCAs are often used to investigate the environmental impact of conventional wastewater systems and compare them with alternative systems. C. Remy examines in his dissertation *"Life cycle* *assessment of conventional and source separation systems for urban wastewater management"* different LCA case studies (Remy, 2010, p. 21ff). Similar to cost comparison methods, in LCA's the functions of the compared systems need to be equal. The results of the work reveal an overall positive impact (e.g. emissions, resource consumption, energy) of alternative over conventional approaches (Remy, 2010).

By definition, iSaS combine conventional with modern resource-oriented approaches. In this regard it can be assumed, that the environmental impact of iSaS will still be reasonably positive (compared to conventional approaches and depending on local conditions and priorities), which is a reason, why LCA's and other tools are not further discussed in the present dissertation. None of the above-mentioned publications specifically refer to the term of *integrated sanitation*.

D.1.2 Advantages of modelling and simulation

Modelling and simulation of sanitation systems have several interesting aspects and advantages for the practical implementation.

Better understanding of the system

In graphical, bloc-based simulation tools, such as Simulink® it is relatively easy to **structure** and **visualise** the complete **system** and its **interface connections**. It is possible to get a **response to** different **user inputs** and **test** their **impacts** on the system behaviour. Models are also robust against environmental changes and external, unexpected influences.

What are the advantages?

By modelling it is possible to **find and fix problems** at a very **early** stage in the planning process of a system. Errors should always be fixed as early as possible. Most of the costs of the construction and the operation phase of an infrastructure system can be saved in the requirement and planning phases.

Varying conditions can be tested in the model, which are difficult to be replicated in the real world. Further on system changes and system conversions can be more easily arranged and combined, as compared to spreadsheet calculations. By this it is possible to **reveal hidden** (e.g. technical, economic) optimisation **potentials** and equally **support understanding** and decision making **by visualisation.** Most of these advantages result in an **enhanced efficiency** and **money saved** over the project lifetime**.**

D.1.2.1 Advantages of Simulink®

MATLAB® and Simulink® are part of a software bundle for numerical computation, visualization, and programming, which is often used by scientists and engineers at many universities and institutes around the world.

Simulink® offers a bloc diagram environment for multi-domain simulation and model-based design. It can handle very large systems with model structures of more than 1 million blocs by organisation of signals and models in variants, libraries, bus signals, and model blocs. It also provides a platform, which is designed to model and simulate controls and signal processing of mechanical, electrical, logical, and other systems. The software is available at many universities and has a broad user community.

The main advantages with regard to the iSaS model are related to the **visualisation** of the model, the **rearrangement** and **structuring** of process steps and signals, as well as debugging functionalities. The model can be structured in systems and subsystems. The **concatenation** and rerouting **of signals** in signal busses facilitates a clearer arrangement and bugs can be found fast, and with more reliability compared to MS Excel®.

D.1.2.2 Disadvantages of Simulink®

Simulink® is a commercial software and not freely available. This can be a significant disadvantage for planners in developing countries, as the tool may not be affordable for them. Similarly, it is a professional and very capable programming environment. Due to the complexity, it is not self-explaining and effort is needed to learn the software. This is one of the reasons, why the software is **not suitable for non-professional users**.

D.1.3 Concept and design of model

Design principles for the model

Some basic design principles were pre-defined for the development of the model. These principles were driven by the motivation to make a complex interaction of interconnected calculations and correlating technical and economic systems as understandable and accessible as possible.

The software-based model should be

- **transparent** and most clearly arranged,
- as **simple** as possible,
- yet designed in a manner close to a **realistic** situation,
- and equally allowing for a **detailed** guidance of material-flows and interconnected monetary-flows.

Further on it should correlate with here-described principles of iSaS and be **adaptable** and extendable.

Use of the software MATLAB®, Simulink®, and MS Excel®

The model is built upon a combined usage of the two software products MS Excel® and Simulink®. The spreadsheet software is only used to organise the basic input parameters, to define assumptions as well as to specify the sources of information and valuate the quality of the used data (see chapter D.2).

As much as possible the user should interact either with the spreadsheet or with the model in Simulink® itself, without being forced to constantly switch between the two for making changes of parameters or analysing results.

NOTE: MATLAB® and Simulink® work entirely numerical. All ***calculated values are unit-less***. It has to be kept in mind to convert all input parameters to the correct dimension and unit. This can be done in the spreadsheet or in the model in Simulink® itself.

D.1.4 Type of model and general system boundaries

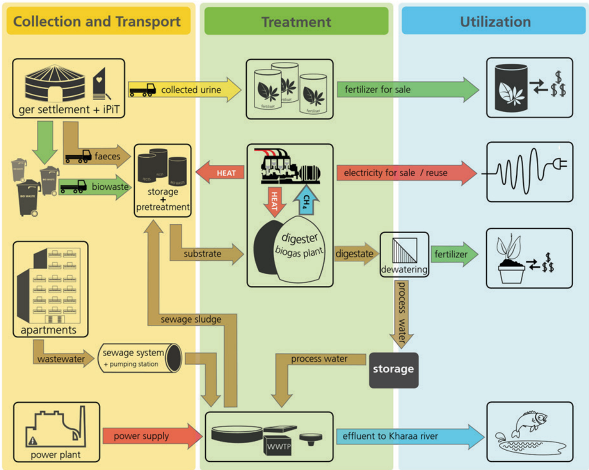
It is obvious to base the model on the theory of material-flow analysis (MFA). According to (Brunner & Rechberger, 2004), the goal of material flow analysis within a company, for instance, is to quantify and then optimize the production processes so that materials and energy are used in a more efficient manner (e.g. in recycling and waste reduction). Companies can use the obtained MFA results to reduce their operational costs and improve environmental performance. Ideally this will be the case for the here-described iSaS, as well.

General system-boundaries of model

Commonly, in each infrastructure project three different development phases can be distinguished in time: planning, implementation, and operation. In order to draw conclusions about the sustainability of a project over its entire lifetime, fully dynamic models are the better choice, as they can have the potential to be designed in a way to be closer to reality. However, such a fully dynamic model becomes very complex and is less suitable for the practical application.

The here-developed model will not distinguish between different development phases of a project. Equally **seasonal changes**, for instance the variation of biowaste composition, or different treatment methods, or varying treatment efficiencies in summer and wintertime, are **not considered** in this model, as it is not intended to examine the systems behaviour over the year. The minimum observation period is set to one year.

Spatial development of the project area shall however be adapted through variations of certain input parameters, such as pipe length, transport distances, and urban areas. The model can therefore be regarded as a **partially dynamic model**. The described **iSaS level 3** *communication-flows, structures, and administration* is equally **not modelled**, as a model based on MFA is not suitable for this purpose. Rather the results of the MFA can be used to facilitate the communication with the stakeholders.



As already described (see repeated Figure left, iSaS model Darkhan), the model will be based on the Darkhan case study. In the following Chapter D.2 (*parameters and processes*) and Chapter D.3 (*structures and use*) the required implementation steps will be described, which were used for the transformation of the theoretical iSaS model into the software-based iSaS model. The result of this development process is presented in Chapter D.4, Figure 59 and further on applied and discussed.

D.2 Parameters and processes in the iSaS model

In this chapter, the main parameters of the material, energy and monetary-flows and the way of their implementation in Simulink® are described. The basic data concerning the process efficiencies and process variables are explained here as well.

All data and indicators presented here are depending on local framework conditions. As much as possible, data has been used, which was gained in the project period in Mongolia. In case of unavailable data or in case indicators could not be derived from the local project data, it is referred to literature values. In all other cases assumptions are made and justified.

Further on, questions have to be answered, concerning the relevant parameters and indicators for the model and the quality of the available data. Examples are:

- Which of the biological, chemical, physical parameters, nutrients N, P, K, C, drugs, chemicals, toxic substances, organic pollutants, heavy metal are actually useful to be considered in the model?
- Which data sources are actually available and how reliable is the data? Are literature values sufficient or is the quality of personally collected data better?
- Do strong variations of data have to be considered, depending on time, location, climate, economy, and other factors? Alternatively, is it acceptable to use constant values?

Example about content variations of primary material-flows faeces & urine based on human diet:

The primary material-flows from the iPiT®s have been assessed in Darkhan and evaluated in (Londong et al., 2014) and (Bruski, 2015). The findings reflect differences between the meat-based Mongolian diet and European diet. The results vary in quantities and content of the faeces. The characteristic of the material-flow faeces is influencing the treatment efficiency of the biogas plant and biogas yield. Such factors are known, but not sufficiently quantified in the Mongolia case.

An interesting example about alternating diets is given in (Renner, 2014): Here, the influence of *1. normal mixed diet with meat, 2. calorie reduced diet,* and *3. normal vegan diet* on the composition of faeces has been examined in an own experiment. It has been found out, that quantities of faeces are highest in a vegan diet, which influenced the daily load of nutrients as well. Due to the higher quantity, the daily biogas yield was roughly 30% higher in the vegan diet compared to the mixed diet in the experiment. Similarly, the nutrient ratio differs depending on the intake of proteins, carbohydrates and fats.

In literature many different values can be found for different countries, as for instance stated in (Bruski, 2015; DWA, 2015; Stäudel, 2008). There are methods to calculate the amounts and composition of human excreta and estimate the average amount of N, P, K in different countries if nutritional habits are known (Jönsson, Stintzing, Vinnerås, & Salomon, 2004) and (WHO/FAO, 2002).

Due to the lack of detailed data, the model often has to refer to accepted standard values. Input parameters can be varied in case of availability of reliable local data at any time. The sources of input data are specified in the input list of parameters for the iSaS model. The user can then decide independently if the data is suitable enough for his or her needs.

D.2.1 Structure of parameters for the iSaS model

Table 7: Structure of system parameters

1. basic input parameter
residents
urban structure
infrastructure
agricultural area
...
2. process parameter & assumptions f. treatment
temperatures
solids retention time
destruction rates
ratios of MF, EF, MonF, and general ratio
...
3. material-flows
water consumption
urine
faeces
greywater Ger area
wastewater apartment
solid waste
biowaste
...
4. energy-flows
electricity
heat
biogas
fuel
...
5. monetary-flows
commercial value NPK
electricity
heating
fuel
costs investment
costs O&M
economic lifetime
cost recovery
...

In the next step, it is necessary to develop an appropriate structure of parameters for the iSaS model.

The structure (as represented in Table 7) is based on the needs of the Darkhan case, but can be adapted for other project areas.

The parameters are clustered in (level 1, main categories):

1. basic input parameter
2. process parameter & assumptions f. treatment
3. material-flows
4. energy flows
5. monetary-flows.

Level 2 (sub categories) orders the parameters according to their type or function. All **parameters**[23] in the model ***are unique***, regardless whether they are *dependent or independent variables*, *parameters*, or *constants*.

The structuring of input parameters is the basis for the MS Excel® spreadsheet, which serves as input file for all the parameters of the iSaS model in Simulink®.

The parameters and their implementation in the iSaS model are described more in detail further below.

D.2.2 Combined nomenclature for parameters – name of variable

All parameters have to follow a specific syntax, so that they can be correctly read and assigned as variables by the import function of Matlab® and written into the Matlab® workspace. On one side, the name of the variables should present precisely their category, subcategory, function, location, and additional information, in order to identify them correctly in the model.

The name of the variable concludes an abbreviation (abbr.) of the main category and subcategories, followed by supplementary information (function, status, etc.). The sequence of the information in the variable name is divided by an underscore "_" and defined as follows:

*abbr-category_abbr-subcategory_abbr-function_* ***or*** *_abbr-of-status_* ***and/or*** *_abbr-other*

The following Table 8 exemplary describes the nomenclature of the variable names.

Table 8: Nomenclature of variables in Matlab® workspace – main categories & examples

category	**abbr.**	**subcategory**	**abbr.**	***parameter - examples***	**name_variable**
1. basic input parameter	**IP**	residents	**res**	1. basic input parameter / residents / total number of residents	***IP_res_tot_num***
2. process parameter & assumptions for treatment (technical parameter)	**TP**	urban structure	**urb**	1. basic input parameter / infrastructure / total road network ger areas	***IP_infra_tot_road_ger***
3. material-flows	**MF**	infrastructure	**infra**	3. material-flows / urine / COD	***MF_urine_COD***
4. energy flows	**EF**	agricultural area	**agri**	3. material-flows / wastewater apartment / Q	***MF_wastewater_Q***
5. monetary-flows	**MonF**	solid retention time	**SRT**	4. energy-flows / fuel / fuel consumption transport ger area	***EF_fuel_consum_ger_C***
...	...	...	...	...	...

All parameters are consecutively listed in a MS Excel® spreadsheet. The spreadsheet is the source of input data for the Matlab® workspace. The **values** of the variables **can be changed** before they are imported to Matlab®. Variable **names should not be changed**, as this would produce error messages when running the simulation.

Some basic calculations of the values are done in the spreadsheet itself, such as **conversions, ratio calculations of dependent variables** and **others** (e.g. ratios of residents in ger areas and apartments buildings, population densities, road network per area, some technical parameters).

"**Bold**" printed values in the spreadsheet indicate values, which are ***entered manually*** and therefore also refer to a specific data source.

"Normal" printed values are ***calculated*** in the spreadsheet based on the manually entered values.

"**Bold orange**" printed variable names indicate that this ***variable is used in the model in Simulink®*** as a constant value.

D.2.3 Basic input parameters – model based on the Darkhan case

The main category "**1. basic input parameter**" summarizes project and location specific data with regard to residents, urban structure, existing infrastructure, agricultural area and more. All data in this category have been gained in the project itself or were calculated by using external sources or tools, such as GoogleEarth® and others.

The assigned variable names start all with the abbreviation "**IP**_xxx_xxx". The following Table 9 shows an example of basic input parameters in the spreadsheet.

Table 9: Parameters, variable names & values – example of basic input parameters

	A	B	C	D	E	F
1		parameter	name_variable	value	unit	attribute
2	1. basic input parameter					
3	residents	total number residents	IP_res_tot_num	100,000	cap	variable
4		ratio apartments	IP_res_ratio_apart	40%	%	variable
5		ratio ger area	IP_res_ratio_ger	60%	%	variable
6		number residents apartments	IP_res_num_apart	40,000	cap	variable
7		number residents Ger area	IP_res_num_ger	60,000	cap	variable
8	urban structure	total area	IP_urb_tot_area	34.0	km2	constant
9		apartment areas	IP_urb_apart_area	3.37	km2	constant
10		ger areas	IP_urb_ger_area	12.53	km2	constant
11		population density apartment areas	IP_urb_apart_density	11,869	cap/km2	constant
12		population density ger areas	IP_urb_ger_density	4,789	cap/km2	constant
13		number of khashaas in ger areas	IP_urb_num_khashaa	10,000	pcs	constant

As the city of Darkhan is changing rapidly in terms of demography, urban structures, population density and others, these parameters need to be verified based on the local development stage. Further on the variation of these parameters are particularly suited to examine different scenarios of the future development of the city.

D.2.4 Process parameters – simplified assumptions for treatment

The main category "**2. process parameter & assumptions for treatment (technical parameter)**" summarizes technology specific data. Some of the values, specifically the ones referring to the biogas plant, are gained in the pilot project. The other values are referring to standard values in literature or are derived from those standard values as assumptions. The assigned variable names all start with the abbreviation "**TP**_xxx_xxx" (see Table 10).

Table 10: Technical process parameters - example

	A	B	C	D	E	F
1		parameter	name_variable	value	unit	attribute
28	2. process parameter & assumptions for treatment (technical parameter)					
29	destruction rates	COD destruction in % at 5d SRT in WWTP	TP_COD_destr_WWTP_5dSRT	44%	%	variable
30		N destruction in % at 5d SRT in WWTP	TP_N_destr_WWTP_5dSRT	20%	%	variable
31		COD destruction in % at 20d digestion time - biogas production	TP_COD_destr_digester	60%	%	variable
32		N destruction in % at 20d digestion time - biogas production	TP_N_destr_biogas	3%	%	variable
33	ratios of MF, EF, MonF, general	ratio of separated urine in apartment buildings	TP_ratio_urine_to_WW_apart	80%	%	variable
34		ratio of Q wastewater loss in sewage system	TP_ratio_WW_total_loss_sewer	30%	%	variable
35		ratio of Q wastewater discharge to Kharaa river	TP_ratio_WW_discharge_Kharaa	97%	%	variable
36		ratio of Q wastewater in sludge to biogas plant	TP_ratio_WW_to_biogas_plant	3%	%	variable

Single processes, such as different treatment steps in the WWTP, substrate conditioning, composting, and other process technologies, are not modelled here. For instance, varying treatment efficiencies of the process steps caused by influent fluctuations (quantities and loads), ammonia inhibition in biogas digester due to high quantities of misguided urine, biowaste composition and change of moisture & C/N ratio and others, are not modelled. The reason is that the model does not need to deliver detailed results, which would allow statements regarding to single process steps. It is sufficient to consider for instance the WWTP as a black box with a defined influence on the respective material-flows. The calculated values are related to an annual observation period.

Therefore, the model works with **fixed treatment efficiencies**, which are idealised and included as constant values. In that sense, the model is simplified and static with regard to process fluctuations. In other words, it is supposed that the treatment processes are working as intended. The values of the variables can be changed, or new variables, which characterise new scenarios, can be added.

D.2.5 Parameters – material-flows and energy-flows

D.2.5.1 Parameters of material-flows – quantities and loads

The main category “**3. material-flows**” summarizes sanitation specific parameters of the main material-flows urine, faeces, greywater, wastewater, and biowaste.

The assigned variable names all start with the abbreviation “**MF**_xxx_xxx” (see Table 11).

Table 11: Parameters of material-flows - example

	A	B	C	D	E	F
1		**parameter**	**name_variable**	**value**	**unit**	**attribute**
40	**3. material-flows**					
41	water consumption	water consumption in apartments	MF_water_cons_apart	265	l/cap/d	variable
42		water consumption in ger areas	MF_water_cons_ger	12	l/cap/d	variable
43	urine	Q	MF_urine_Q	1.37	l/(cap*d)	constant
44		TS	MF_urine_TS	57	g/(cap*d)	constant
45		TVS	MF_urine_TVS	41	g/(cap*d)	constant
46		BOD_5	MF_urine_BOD	5	g/(cap*d)	constant
47		COD	MF_urine_COD	10	g/(cap*d)	constant
48		N	MF_urine_N	10.4	g/(cap*d)	constant
49		P	MF_urine_P	1.0	g/(cap*d)	constant
50		K	MF_urine_K	2.5	g/(cap*d)	constant
51	faeces	Q	MF_faeces_Q	0.14	l/(cap*d)	constant
52		TS	MF_faeces_TS	38	g/(cap*d)	constant

Characteristic values for iSaS model of primary material-flows

The compositions of the material-flows urine, faeces and greywater are depending on the local Mongolian diet and other local aspects. Although some ideas about the varying compositions of these material-flows have been collected in Darkhan, this data is not sufficiently supported statistically. For greywater, it is actually not possible to determine a standard characteristic in

Mongolia due to the local habits, such as use of strong chemical detergents, frequent home-based slaughtering of animals, and extremely varying water consumption.

It is therefore decided to include only accepted standard values from literature as input parameters for the model. The standard values are described in (DWA, 2014), (DWA, 2015) and (Bruski, 2015). These values can be modified at any time to fit to the local conditions if reliable data is available (see Table 12).

Table 12: Characteristic annual values of specific loads of the material-flows urine, faeces and greywater per capita compiled from (DWA, 2015)

<table>
<tr><td colspan="6">Characteristic annual values of specific loads of primary material-flows per capita</td></tr>
<tr><td colspan="2">parameter
(median values)</td><td>unit</td><td>urine</td><td>faeces</td><td>greywater</td></tr>
<tr><td colspan="2">Q</td><td>l/(cap*a)</td><td>500</td><td>51</td><td>39,420</td></tr>
<tr><td colspan="2">TS</td><td>kg/(cap*a)</td><td>20.8</td><td>13.9</td><td>25.9</td></tr>
<tr><td rowspan="3">organic matter</td><td>TVS</td><td>kg/(cap*a)</td><td>15.0</td><td>12.8</td><td>16.1</td></tr>
<tr><td>BOD_5</td><td>kg/(cap*a)</td><td>1.8</td><td>7.3</td><td>6.6</td></tr>
<tr><td>COD</td><td>kg/(cap*a)</td><td>3.7</td><td>21.9</td><td>17.2</td></tr>
<tr><td rowspan="4">nutrients</td><td>N</td><td>kg/(cap*a)</td><td>3.80</td><td>0.55</td><td>0.37</td></tr>
<tr><td>P</td><td>kg/(cap*a)</td><td>0.37</td><td>0.18</td><td>0.18</td></tr>
<tr><td>K</td><td>kg/(cap*a)</td><td>0.91</td><td>0.26</td><td>0.37</td></tr>
<tr><td>S</td><td>kg/(cap*a)</td><td>0.26</td><td>0.07</td><td>1.06</td></tr>
</table>

The **main characteristic parameters** (highlighted in green) of the material-flows, which need to be considered **in the model, are Q, COD, N, P, and K**. They are used as input parameters, multiplied with the number of users and concatenated in signal buses for the simulation (see Chapter D.3.1.1).

There is no reliable data existing about the composition of domestic wastewater in Darkhan, as influent of domestic wastewater into the WWTP is not examined. Only the high average water consumption of the residents in apartment buildings is known. The water consumption is also a parameter, which is about to change in the near future due to the installation of water meters and a different fee system in the city.

The characteristic of domestic wastewater is therefore calculated on the basis of the other material-flows and the water consumption. Further on it is assumed, that untreated industrial wastewater will be removed from the domestic wastewater stream, as it is contaminated with heavy metals and other toxic chemicals. Value added from the iSaS in Darkhan is only useful, if **industrial wastewater is excluded** in order to prevent from sludge contamination.

Characteristic values for iSaS model of other organic material-flows

In and around Darkhan a lot of livestock is produced and consumed. So far, the organic waste from livestock (manure, slurry, slaughterhouse waste or other organic matter) is not used and wasted in Darkhan. It could potentially be included in the biogas plant as an energy-rich substrate.

Unfortunately, there is no information about the quantity of available livestock wastes. Organic livestock waste streams are therefore not included in the model at this stage. Table 13 summarizes some literature values of the organic waste material, which is prevalent in Darkhan.

Table 13: Selected organic waste material (mean values in TS) after (Ottow et al., 1997, p. 143)

raw material	loss on ignition [%]	C/N ratio [-]	N [%]	P_20_5 [%]	P [%]	K_20 [%]	K [%]
kitchen waste	20-80	12-20	0.6-2.2	0.3-1.5	0.13-0.66	0.4-1.8	0.33-1.49
biowaste (min max values)	30-70	10-25	0.6-2.7	0.4-1.4	0.18-0.62	0.5-1.6	0.42-1.33
wastewater sludge (stabilised)	15-30	15	2.3	1.5	0.66	0.5	0.42
wastewater sludge (raw)	20-70	15	4.5	2.3	1.01	0.5	0.42
manure							
- cattle	20.3	20	0.6	0.4	0.18	0.7	0.58
- horse	25.4	25	0.7	0.3	0.13	0.8	0.66
- sheep	31.8	15-18	0.9	0.3	0.13	0.8	0.66
- pig	18.0	-	0.8	0.9	0.40	0.5	0.42
slurry							
- cattle	10-16	8-13	3.2	1.7	0.75	3.9	3.24
- pig	10-20	5-7	5.7	3.9	1.72	3.3	2.74
- chicken	10-15	-	9.8	8.3	3.65	4.8	3.98
- sheep, goat	20-30	-	-	-	-	-	

Biowaste from domestic sources is included in the model and animal waste can be added in case of data availability.

D.2.5.2 Parameters of energy-flows

The main category "**4. energy-flows**" summarizes specific parameters for the modelling of energy-flows. These are mainly the energy carriers: fuel, heat or electricity, as well as biogas. As energy is either **c**onsumed by a process (e.g. fuel for transport, heating of digester, heat for thawing of material-flows from ger areas, electricity for pumping stations or the WWTP) or **p**roduced (biogas in digester or electricity in CHP), the variable name gets the attribute "**C**" for "*consumed"* or "**P**" for "*produced"*.

The assigned variable names all start with the abbreviation "**EF**_xxx_xxx_P" or "**EF**_xxx_xxx_C" (see Table 14). Energy is included in the form of secondary energy (heat, electricity, biogas), which is directly used or produced within the system. Primary energy sources are not considered in this work.

Table 14: Parameters of energy-flows - example

	A	B	C	D	E	F
1		parameter	name_variable	value	unit	attribute
87	**4. energy-flows**					
88	biogas	methane NL - production	EF_methane_TOC_P	1.81	NL/(gTOC)	constant
89		biogas NL - production per kg TVS	EF_biogas_TVS_P	0.4	NL/(gTVS)	constant
90	fuel	fuel consumption transport Ger area	EF_fuel_consum_ger_C	10	L/100km	constant
91		fuel consumption transport storage / farmland	EF_fuel_consum_agri_C	10	L/100km	constant
92	heat	biogas plant - conditioning substrate, thawing faeces - consumption - winter	EF_heat_biogas_condit_C	5.77	kWh/(cap*d)	constant
93		biogas plant - digester - heat - consumption	EF_heat_biogas_process_C	0.79	kWh/(cap*d)	constant
94		biogas NL - heat value per Nm3 biogas - production	EF_heat_value_biogas_P	6.5	kWh/Nm3	constant

There is a significant uncertainty related to the modelling of the energy-flows, as the values have to be mostly derived from literature values and cannot be verified with regard to local peculiarities. For instance, the building of the accepting station for faeces, the conditioning and the biogas plant has to be imagined while hardly knowing anything about the building dimensions and the construction materials, which would be used in reality. Further on different treatment technologies have different energy needs, which is another reason why the model sticks to the described Darkhan case and does not consider alternative solutions at this point.

Energy is expressed in physical work, internal energy (or heat), electrical power or biogas. Specific values of energy consumption (or production) are for instance:

a) kWh : e.g. internal energy (heat) or electrical power
b) kWh/m^2 : e.g. energy loss relative to the surface of the accepting station building
c) kWh/cap/d: e.g. heat consumption relative to PE and day
d) kWh/m^3 : e.g. electricity consumption for pumping of 1 m^3 wastewater
e) NL/g/COD: biogas production in NL per g COD removed

Most of the values concerning energy production and consumption with regard to the biogas plant have been examined already in the dissertation of Bruski, C. (2015). These values are used equally in the model presented here.

Fuel consumption for transport of material-flows is included in the monetary-flows with local prices, as this energy carrier is not related to the treatment processes at the WWTP.

D.2.6 Parameters – monetary-flows and potential value of NPK

The main category "**5. monetary-flows**" summarizes specific parameters for the modelling of monetary-flows. These include investment costs as well as costs for operation and maintenance (O&M). As much as possible, data from the project in Mongolia is included. Further on missing values have been derived from data that has been gathered recently. The prices for fuel and electricity are actual and based on information from the first half of 2016. Investment costs and O&M are described further below in this chapter.

The assigned variable names start all with the abbreviation "**MonF**_xxx_xxx" (see Table 15).

Table 15: Parameters of monetary-flows - example

	A	B	C	D	E	F
1		parameter	name_variable	value	unit	attribute
153	5. monetary-flows					
154	commercial value NPK	N	MonF_N	0.89	€/kg	variable
155		P	MonF_P	1.81	€/kg	variable
156		K	MonF_K	0.67	€/kg	variable
157	electricity	electricity large consumer tariff	MonF_elec	0.061	€/kWh	variable
158	heating	central heating supply	MonF_heat	0.216	€/m2m	variable
159	fuel	fuel cost transport Ger area	MonF_fuel_ger	0.806	€/L	variable
160	investment costs	planning costs, detailied design, supervision of implementation in % of total investment costs	MonF_invest_consultant	15%	%	constant
161		iPiT®	MonF_invest_ipit	710	€/pcs	variable
162		greywater trickling filter - sink whole	MonF_invest_greywater_filter	50	€/pcs	variable

The main idea behind the economic sustainability of iSaS is related to the value-added reuse of the material-flows and therein the primary macronutrients NPK. It is therefore worthwhile to take a closer look at their economic potential. In the next chapter D.2.6.1 the potential commercial value of NPK is examined in detail.

D.2.6.1 Potential commercial value of nutrients N, P, K

The main resources with a commercial value contained in the material-flows of iSaS are the plant nutrients N, P, K. These so-called primary macronutrients appear in the model in the form of the quantity of their elements. Based on market prices for commercially available fertiliser products, the economic value of NPK, but also other macronutrients, such as S and Mg, can be estimated. It is therefore worthwhile to have a closer look at the development of market prices and the composition for selected fertilizers. When doing so, it becomes apparent that an estimation of the commercial value of NPK and other nutrients is difficult to undertake.

Commodities: Global nominal market prices of selected fertilisers as basis for the determination of a potential commercial value of macronutrients

Firstly, the world market prices for fertiliser products fluctuate a lot, as can be seen in Figure 51 and this is due to several reasons: Not only (over) supply and demand can be named as important factors for fertiliser prices. They are also depending on varying access to mineral deposits, financial speculations and crisis respectively and are bound to global energy prices. Further on, fertilizer prices can also show a big deviation in local markets, such as in Germany (see Table 16).

The graphs in Figure 51 represent the development of market prices of major fertilizers, which stand exemplary for the vast amount of different varying chemical fertilizers over the last 20 years. The data is raised and provided by the World Bank. The peaks around the year 2007 and 2008 are related to speculations with agricultural products ahead of the world financial crisis and high energy prices. Equally, the recovery in prices in the recent years can be seen, as well as the decline at the end of 2015, which is mainly related to the current low of oil and energy prices respectively.

At this point, the question needs to be raised, which prices in time could actually be used for the iSaS model, as they would always be encumbered with uncertainty.

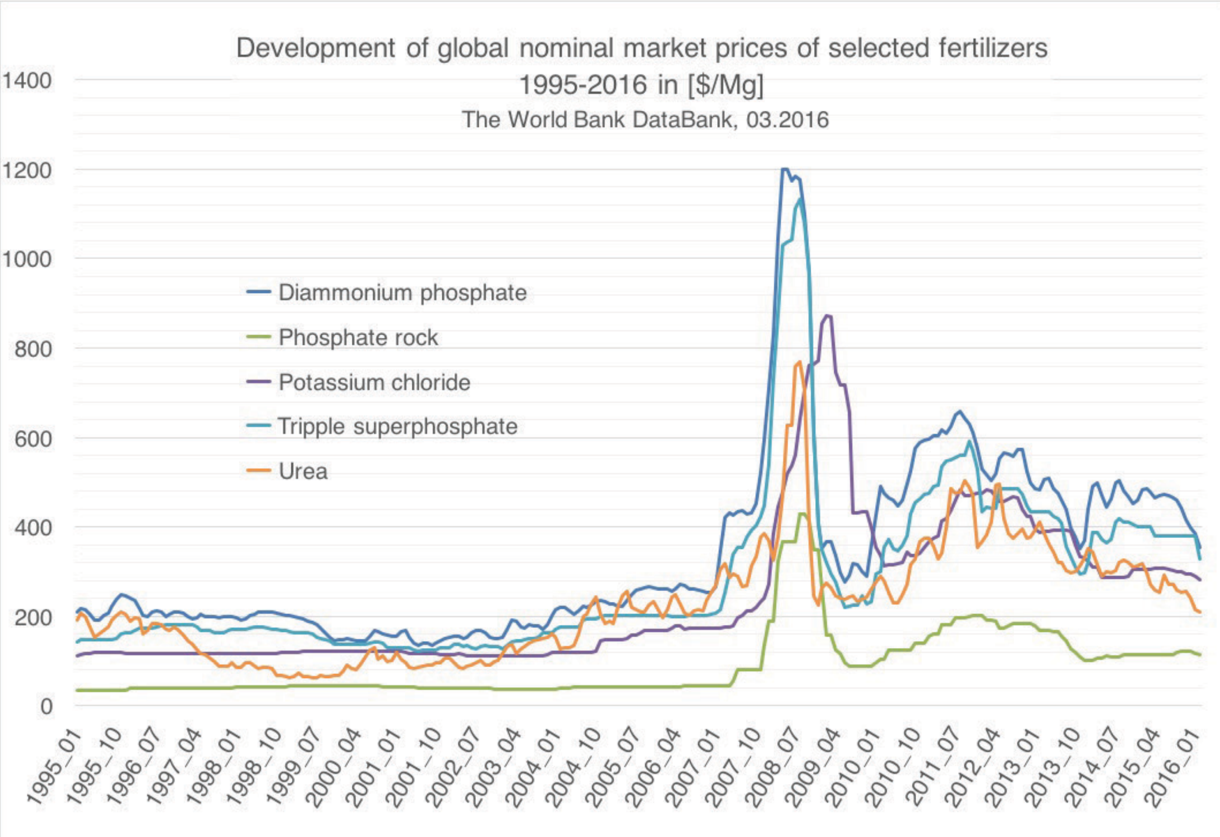


Figure 51: Global nominal market price fluctuation for fertiliser products over 20 years

As prices fluctuate a lot and represent only a temporary snapshot of an economic market situation, it has therefore been decided to choose available prices from a recent but fairly stable market situation from the second half of 2015. For all considered fertiliser products, the month of July has been chosen and the available world market prices have been put in the context of local prices from Germany (see Table 16).

Secondly, not only is a huge variety of chemical fertiliser products available, which differ depending on the source of raw minerals used in the production processes and depending on the application goal. The products can also be distinguished in one-component fertilizers (with one effective element) and multi-component fertilisers (with two or more effective elements). In order to ensure the transferability of the evaluated prices to the iSaS model, they have to be related to the contained quantity of the effective elements NPK, and not to other chemical forms, such as P_2O_5 or K_2O.

In (Dockhorn, 2007, pp. 18–19) it is stated, that the specific price of the effective element from multi-component fertiliser would be the sum of the price of the effective element from one-component fertiliser, given that local influences (e.g. VAT, middlemen) on price increases are eliminated.

Table 16: Fertilisers and their element-specific potential commercial value

	price [€/Mg]	price [€/Mg]	content of nutrient element [%]							specific price of nutrient [€/kg]		
Fertiliser	**July 2015**	**July 2015**	**N**	**P_2O_5**	**P**	**K_2O**	**K**	**S**	**Mg**	**N**	**P**	**K**
calcium ammonium nitrate (CAN)		276[2]	27							1.02		
urea	**249**[1]	325	48							0.68		
urea ammonium nitrate solution (UAN)		255	28							0.91		
diammonium phosphate (DAP)	**427**	535	18	46	20					0.87	1.87	
40 potassium magnesium + MgO (50% K_2O + 6% MgO)		278				50	42		4			0.67
potassium magnesium sulfate		420 - 460				22	18	21	11			2.41 [3]
potassium chloride	**278**					60	50					0.56
triple superphosphate	**346**	420 - 500		45	20						1.75	

[1] Prices labelled in **green colour** are taken from www.indexmundi.com based on The World Bank DataBank
[2] Prices labelled in red colour are taken from www.agrarmarkt-nrw.de based on statistics from the Chamber of Agriculture, Nordrhein-Westfalen, Germany. The last-mentioned values are used for the calculation of the specific price for reasons of comparability.
[3] The high specific price is an outlier, presumably related to high costs of the production process of phosphoric acid. The median value of potassium compared with other sources is plausible.

A similar approach is taken here, but other data sources have been used and verified. Knowing about the uncertainty of the determined specific prices for the effective nutrients NPK, as presented in Table 16, the median specific price has been calculated and summarized in Table 17. The calculated specific price stands for the potential commercial value of the primary macronutrients contained in the material-flows of iSaS. These specific prices will be further on used in the iSaS model as basic values.

Table 17: Potential commercial value of primary macronutrients NPK (median)

Nutrient element	**Specific price [€/kg]** (07.2015)
N – nitrogen	0.87
P - phosphorus	1.81
K – potassium	0.67

For the sake of completeness, it has to be said, that this potential commercial value does not reflect the real fertilising value for a farmer in practical application. The reason, despite the here mentioned uncertainties, is the difference of nutrient plant availability of high soluble chemical fertiliser compared to organic fertiliser products from a wastewater treatment processes or an iSaS. The notion “potential commercial value” should be taken literally. Nevertheless, it is more than sufficient to point out economic potentials of the respective sanitation concept.

Certainly, for the practical assessment of iSaS (or other sanitation concepts), it is recommended to update these values according to the real local market situation. In case such local data is not available (which is often the case in developing countries), the here determined values could be used as reference basis.

Other macronutrients

Despite the chemical elements contained in organic matter C, O, H, N, also the chemical elements P, K, Mg, S, Na, Ca, and Fe belong to the macronutrients, which are essential to all living organisms. They are required by plants to grow and are therefore equally important for their sufficient supply with nutrients (Eitinger et al., 2007, p. 157 f.). Depending on the soil quality they play different roles in the fertilising strategy for agricultural purposes.

Most of these macronutrients therefore have a potential commercial value in the consideration of iSaS. For instance, in (Dockhorn, 2007, p. 19) a specific price for Mg of 0,67 €/kg and S of 0,19 €/kg is described based on data from 2005. However, as Mg, S, Na, and Fe are usually available in most agricultural soils in sufficient quantities, they rarely impose a limiting factor for plant growth.

Among many different forms of industrial utilisation, Ca (in the form of calcium oxide) is used as a pH-value-regulator of acidic soils (liming) and is important in many bio-chemical processes in plant growth. Hence, its role with regard to the preservation of soil fertility and fertilisation in agricultural soils is equally important. In the here considered material-flows Ca is contained in a much lower quantity compared to N or P (Koppe & Stozek, 1999) and has also a lower commercial value compared to NPK fertilisers. Processes of reutilisation of Ca and Mg from wastewater streams, apart from recycling of products from the precipitation of P in the WWT process, are not known to the author.

Because of the higher availability of these macronutrients (Mg, S, Na, Fe, Ca) and lower commercial value, they are regarded as less significant in the modelling of iSaS. The model focuses on the primary macronutrients N, P, K, as they are the main parameters with the highest commercial potential, high potential of negative environmental impact (N, P) and, in the case of P, uneven global distribution and limited availability.

D.2.6.2 Investment costs

Investment costs are to a large extent based on the prices, which were gathered within the timeframe of the project in Mongolia. This includes for instance unit costs for the iPiT® and the transport system, costs for construction (e.g. sewer, storage, biogas plant, WWTP) and other costs.

The investment costs for the WWTP and the biogas treatment facility (including accepting station, conditioning, bin cleaning machine, biogas digester) are estimated based on German standard values and experience. Most of the technical components have to be imported. Equally, construction costs do not have a significantly lower price level in Mongolia, compared to Germany. This is mainly caused by high costs for some construction material, which also has to be imported. Therefore, it is assumed that the standard values lie within a realistic range.

Financial costs, capital costs, costs for shipping and customs clearance as well as VAT are not explicitly stated in the model. They could be either included in the lump sum prices or added later to the model or the MS Excel® spreadsheet. Further on changes in investment costs, price growth rates, interest rates on investment, as they would be considered in a dynamic cost comparison calculation (CCC), are currently not modelled.

The reason for this is that a detailed financial mathematical calculation of the monetary-flows within the model would hide the fact that many of the input values are based on uncertain assumptions. As the model is not used for decision making by comparing different variations of a sanitation system, the CCC approach would equally be overdrawn.

However, the consideration of the investment costs within the model include costs for the participatory planning, detailed design, implementation, total initial investment and costs for re-investment over a harmonized economic lifetime of the iSaS as well as the conventional system. All **investment costs are annualized** and can therefore be used **to calculate present values** of the sanitation system for ger areas and apartment areas, respectively.

D.2.6.3 Operation and maintenance

Similarly to investment costs, O&M costs are also based on prices, which were gathered in the project in Mongolia. These include for instance unit costs for salary, capacity development measures, public relations, institutional restructuring and administration. Further on are included running costs for the transport service, the maintenance of the iPiT®s, storage facilities, acceptance station, conditioning, biogas plant, WWTP and others. These costs are calculated based on the specific input parameters (e.g. length of road, number of connected households, member of staff, costs for fuel).

The maintenance costs are expressed in % of the initial investment costs per year. According to Halbach (2003) maintenance and material costs in Germany can be estimated with 0.5% and 0.6 % of investment costs per year respectively (Halbach, 2003, p. 75). Due to the extreme climate and exposure it is assumed, that this ratio is higher in Mongolia. The residents of the ger areas can contribute to mitigate high costs for maintenance of the iPiTs.

Also, the costs for **O&M are** harmonized over the economic lifetime of the respective system and **annualized** in order to be able **to calculate present values**.

D.2.6.4 Energy costs

Energy costs are included in the form of costs for the consumption of the energy carriers: fuel, heat or electricity. Fuel is needed for the transport system, electricity for pumping stations and the processes in the WWTP. In the biogas plant energy is produced in the form of biogas and then transformed to heat and electricity. This produced energy can be used to replace some of the energy needs of the WWTP and the digester. Supplementary heat from the central thermal power plant can be used to cover the additional needs of the treatment facilities.

Currently in Mongolia there is no incentive system, which supports the transition towards a more sustainable energy supply system. Renewable energies are almost exclusively known on a private level by the use of photovoltaic cells for decentralised and independent electricity production. The big national energy supply systems, mainly electricity and combined heat power plants, do not yet include renewable energy production.

Energy costs are expressed in *€/L diesel* or *€/kWh electricity* or *€/kWh heat*. In the model, it is possible to examine different scenarios with rising or falling energy prices. Their influence on the operation of the system and on related economic results can be assessed. This is advantageous, as it can support the political and economic decision-making. Changing energy prices illustrate changes in a system in a more practical manner than for instance changing prices for fertiliser, because everybody has made this experience before and is directly affected.

D.2.6.5 General remarks on the economic analysis

The model focuses on the practical implementation from an applied engineering perspective, rather than to deliver statements concerning the ecological footprint of the examined system.

As much as possible the included costs are reflecting a price level from 2015 / 2016. One challenge with older prices is the fact that Mongolia experiences a longer period (since 2011) of recession accompanied by a devaluation of the local currency MNT. In January 2011, the currency rate was roughly 1 € = 1,610 MNT, whereas in August 2016, it was in a range of 1 € = 2,500 MNT. The current level of prices for construction material, imported goods, salary and basic services is not known.

D.3 Structure and use of the model in Simulink®

In this chapter, the principle structure of the iSaS model in Simulink® is presented. Further on the use of the model is explained in its fundamentals. This includes a description of the graphical interface of the model and its structuring into systems and subsystems, as well as the import of parameters, selection and running of scenarios and display of selected results.

D.3.1 Graphical interface in Simulink® - systems and subsystems

The graphical interface allows for a better visual understanding of the system and its interconnected processes. As the interface is based on blocs, it is relatively simple to rearrange structures, as well as duplicate, modify and complement similar parts of the model.

D.3.1.1 Integration of parameters

The model almost entirely uses variables, which are specified as parameters in the spreadsheet. This allows for a flexible implementation of every parameter at any location in the model and ensures that the correctly assigned value is always used in the calculation.

Most parameters are included as constant values, as only a small amount of them are dynamically simulated in the modelled scenarios or are directly selectable in model. Most of the values remain static, as for instance the basic parameters of the material-flows.

The following example in Figure 52 shows the implementation of the basic parameters of the material-flow faeces. Firstly, the values are multiplied with the number of residents and converted to the suitable unit. Secondly the parameters are concatenated in one signal bus.

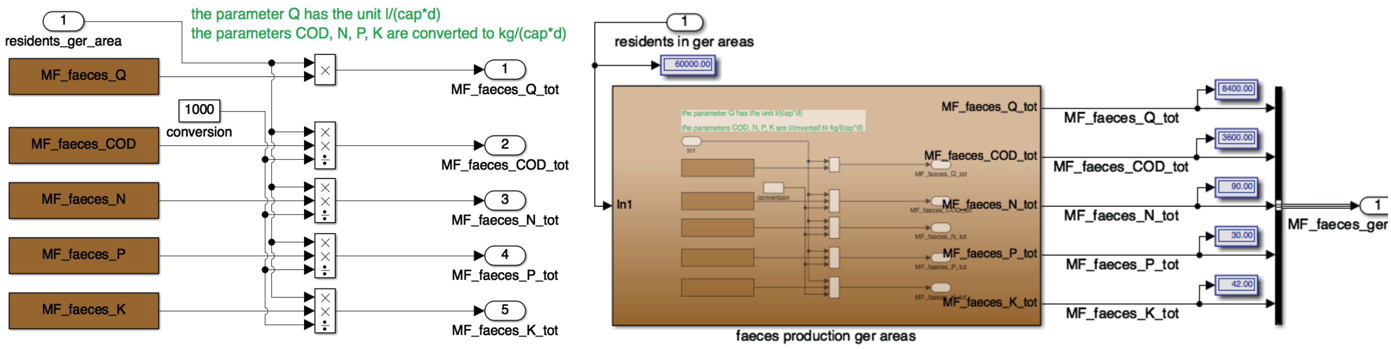


Figure 52: Material-flow faeces - input variables and concatenation in signal bus - example

D.3.1.2 Systems and subsystems

The organisation of blocs and calculations in the form of ***systems*** is important to structure the model and preserve clarity. Figure 53 shows the system of the biogas plant and its containing subsystems.

Subsystems represent levels below the overlying system. Systems and subsystems can contain an unspecified number of further levels of subsystems. Subsystems are needed to structure complex models. Figure 54 shows the lowest level of the subsystem for the WWTP Darkhan with incoming and outgoing signal ports.

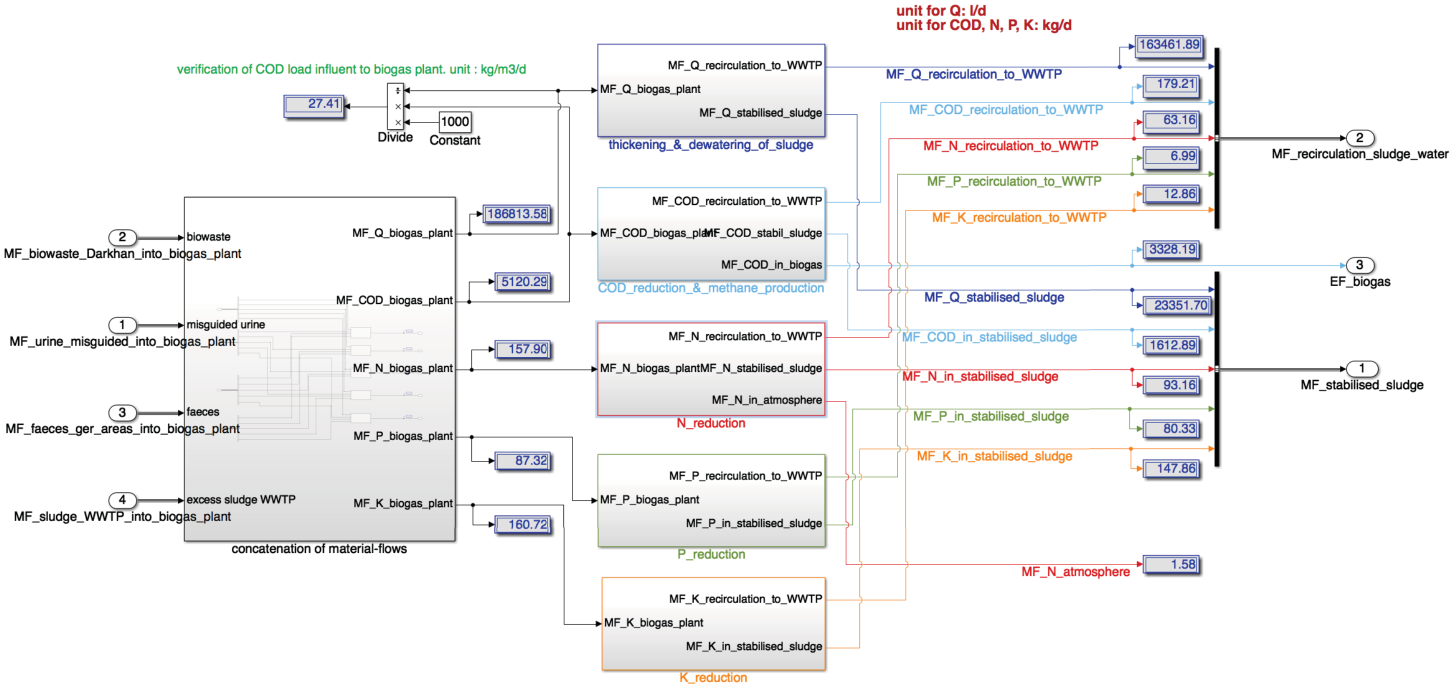


Figure 53: System of biogas plant with different subsystems

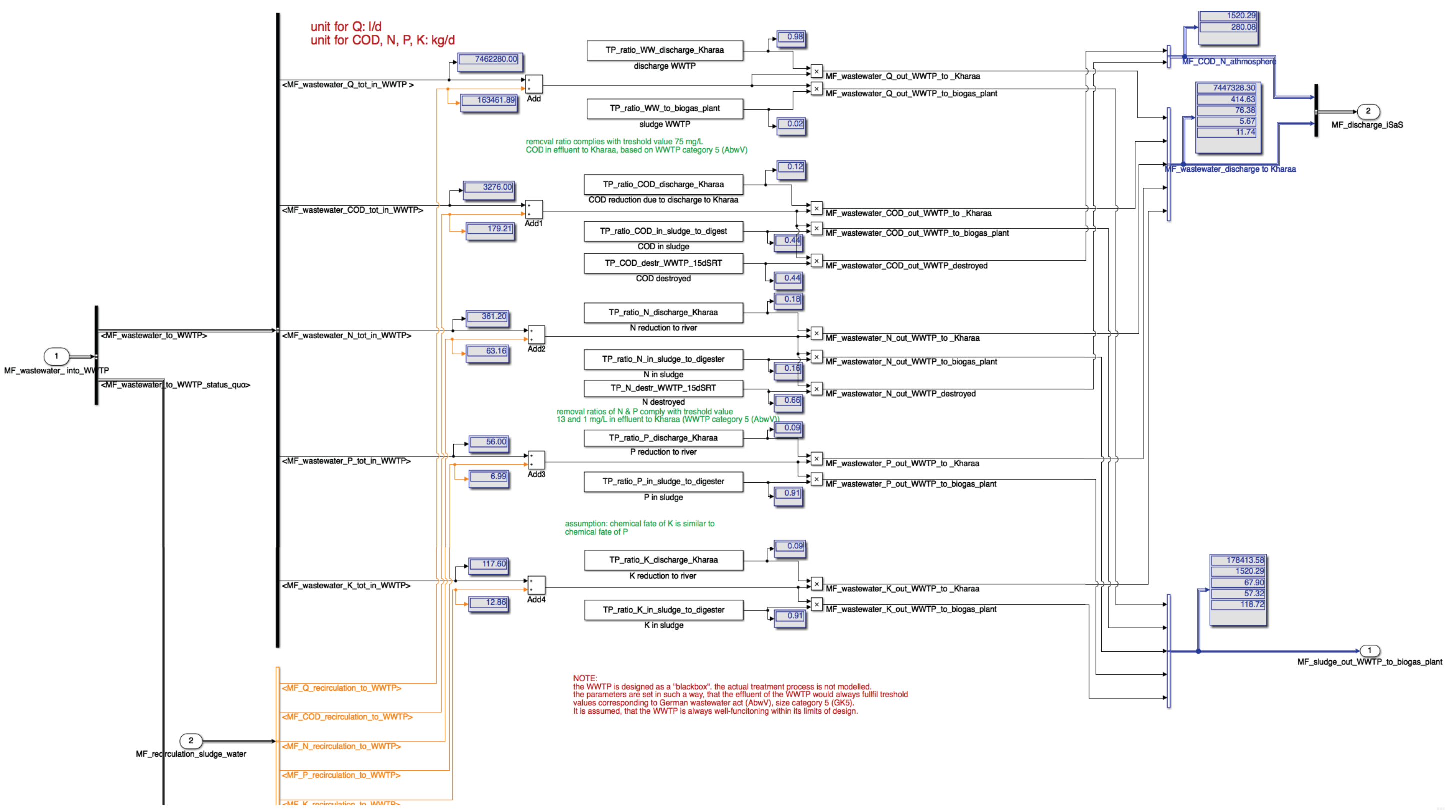


Figure 54: Subsystem - simplified model of WWTP Darkhan

Systems and Subsystems can be masked to either display information about the system in form of text, a symbol or a picture, or on the other hand to specify local variables. These local variables are defined in the mask editor and become available for all subsystems below the mask. Systems and subsystems can be rearranged and modified similarly to the predefined blocs.

D.3.2 Input, simulation and output of data

D.3.2.1 Input of data

In a first step the predefined input parameters from the excel-file have to be imported to the Matlab® workspace prior to the start of the simulation. A Matlab® import script facilitates the assignment of variables and makes them available for the model in Simulink®. An excerpt from the import script and the assigned variables in the Matlab® workspace is displayed in the screenshot Figure 55.

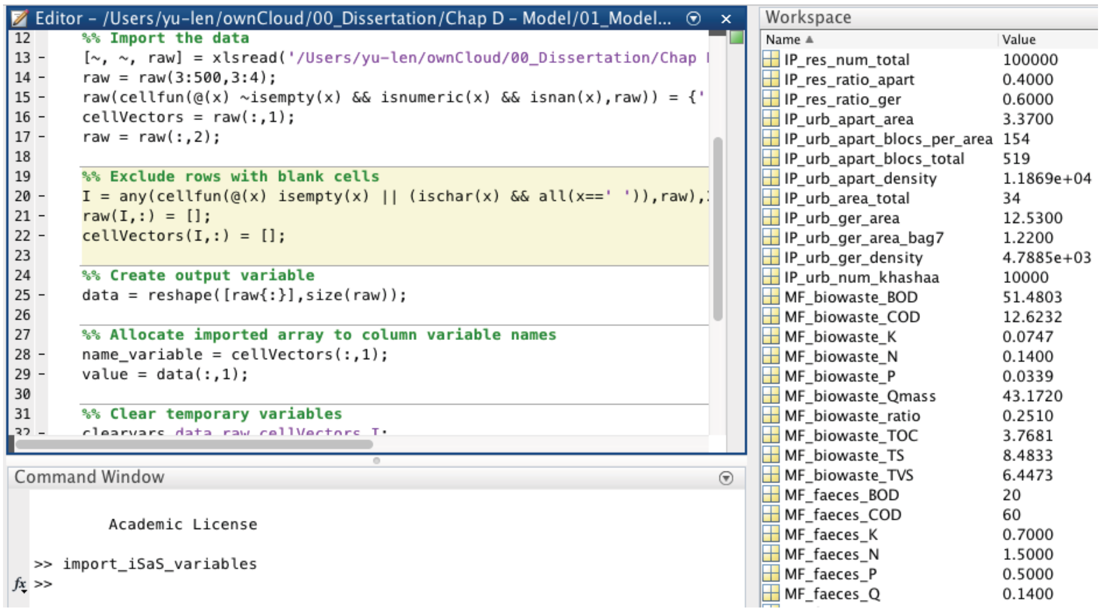


Figure 55: Matlab® import script and assigned variables in the Matlab® workspace

The path of the *import_iSaS_variables.m*-file has to be added to the Matlab® folder organiser. The import script can then be executed by typing the command “ `import_iSaS_variables` “ into the Matlab® Command Window.

D.3.2.2 Simulation and display of data

A second possibility is to import the variables into the Matlab® workspace directly from the model in Simulink®. The model can then be run directly after the import and assignment of the variables.

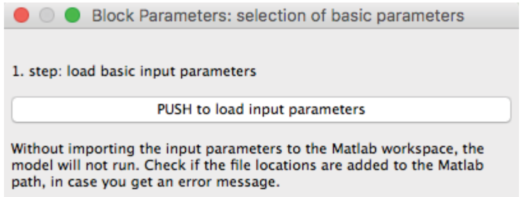


Figure 56: Load input parameter

Simulink® offers a variety of possibilities to display, inspect and log data to the Matlab® workspace or to save the data in a mat-file for future evaluation respectively. Often it is convenient to display data directly in the model, particularly during the development phase. For crosschecking of the calculations, it can even be essential to have a quick overview of the resulting values after a simulation run. Errors and wrong programming can be found more easily and can be eliminated at an early stage.

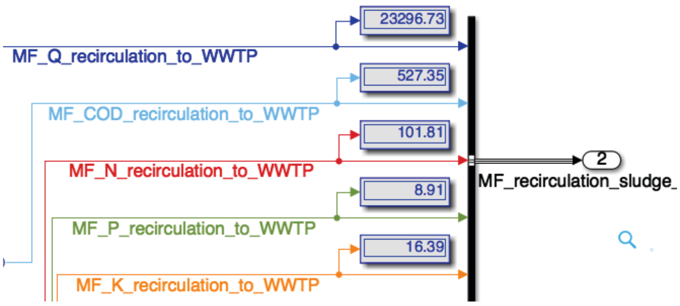


Figure 57: Display of signal values in model

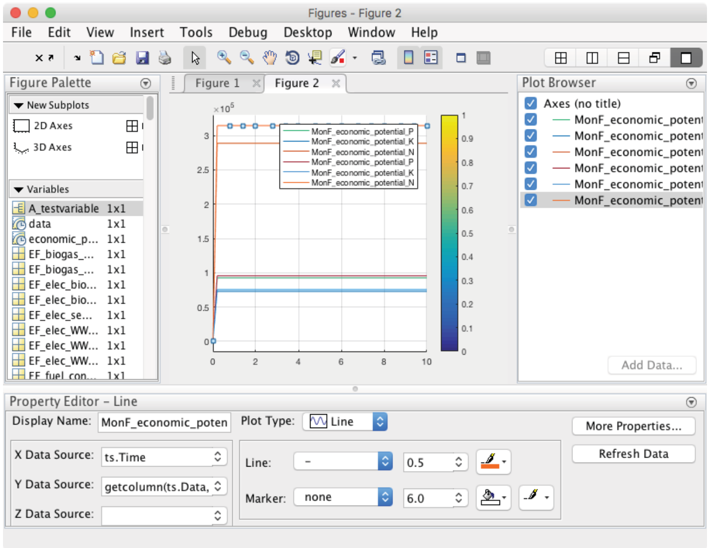
For this purpose, Simulink equally offers a variety of possibilities to show and check the data. Most commonly scope blocs are used to display simulation results. In this model, the “display”-bloc is used to verify the signal values and crosscheck the calculations for plausibility. The display-bloc as shown in Figure 57 can be used for single signals or signal buses and is updated with each simulation run.

D.3.2.3 Output and analysis of data

The export function in an xls-file shows some compatibility issues between the macOS version of Matlab® R2016a and MS Excel®. It has therefore been decided to not include the possibility of direct data export to xls-files in the model presented here.

It is however possible to compare different simulation runs and analyse the results directly in the software with different tools for data inspection and analysis. An example of the figure editor window is shown as screenshot in Figure 58.

The bloc-based visualisation offers the chance to **log** and analyse **data at any location** within the model. This provides each user a unique possibility to examine those parts of model, which are of special interest or of particular value for his or her work.



A purely numerical computation or spreadsheet-based calculation is much less capable of accessing data in an easy way at intermediate steps. Data can be gained from the top level of the model or only partially from systems or subsystems.

Figure 58: Data inspector / figure tool to analyse

D.3.2.4 Adjustment and extension of model

Practically the possibility of ubiquitous data logging and the organisation in systems and subsystems respectively is important, if multiple users intend to share the development work. Each user (*or developer*) is able to focus on different areas and tasks within the model. For instance, one user can work on an enhanced implementation of the biogas plant subsystems, whereas another user refines the economic calculations.

The verification and fine-tuning of the input parameters and their corresponding values in the MS Excel® spreadsheet is the simplest way of adjusting the model. The extension of the model should on one side be done by including additional treatment processes, as well as completing and refining the economic calculation.

The identification, implementation and testing of additional suitable scenarios are further important steps for an extension of the model. The model developed here can serve as a basis for the future realisation of these suggestions.

D.4 Modelling and varying the case of Darkhan

The case study of Darkhan is used to demonstrate the development of a model on the basis of the iSaS principles. In particular, the combined consideration of material-flows, energy-flows and monetary-flows in one model, is uncommon.

D.4.1 The Darkhan case in Simulink®

For the development of such a model, the Darkhan case is particularly suitable because of several reasons:

- The split situation of urban structures limits the number of realistic variations of an overall sanitation solution for the city.
- The climate equally limits the number of treatment processes, which are fitting for the situation in Mongolia.
- Too many variation possibilities easily lead to a very complex model, which could be hardly usable anymore.

The limitations of the case study help to focus the development work on the model itself, without getting caught up too much in numerous possibilities. Still, the model includes the functionality to change some pre-defined parameters and set a few scenarios. Many more scenarios and assessments of the dynamic behaviour of further parameters are thinkable. Such an extended functionality has to be built into the model according to the particular needs of the user. Consequently, the model will remain a work in progress. A complete overview of the current development stage of the model (top level) is illustrated in Figure 59.

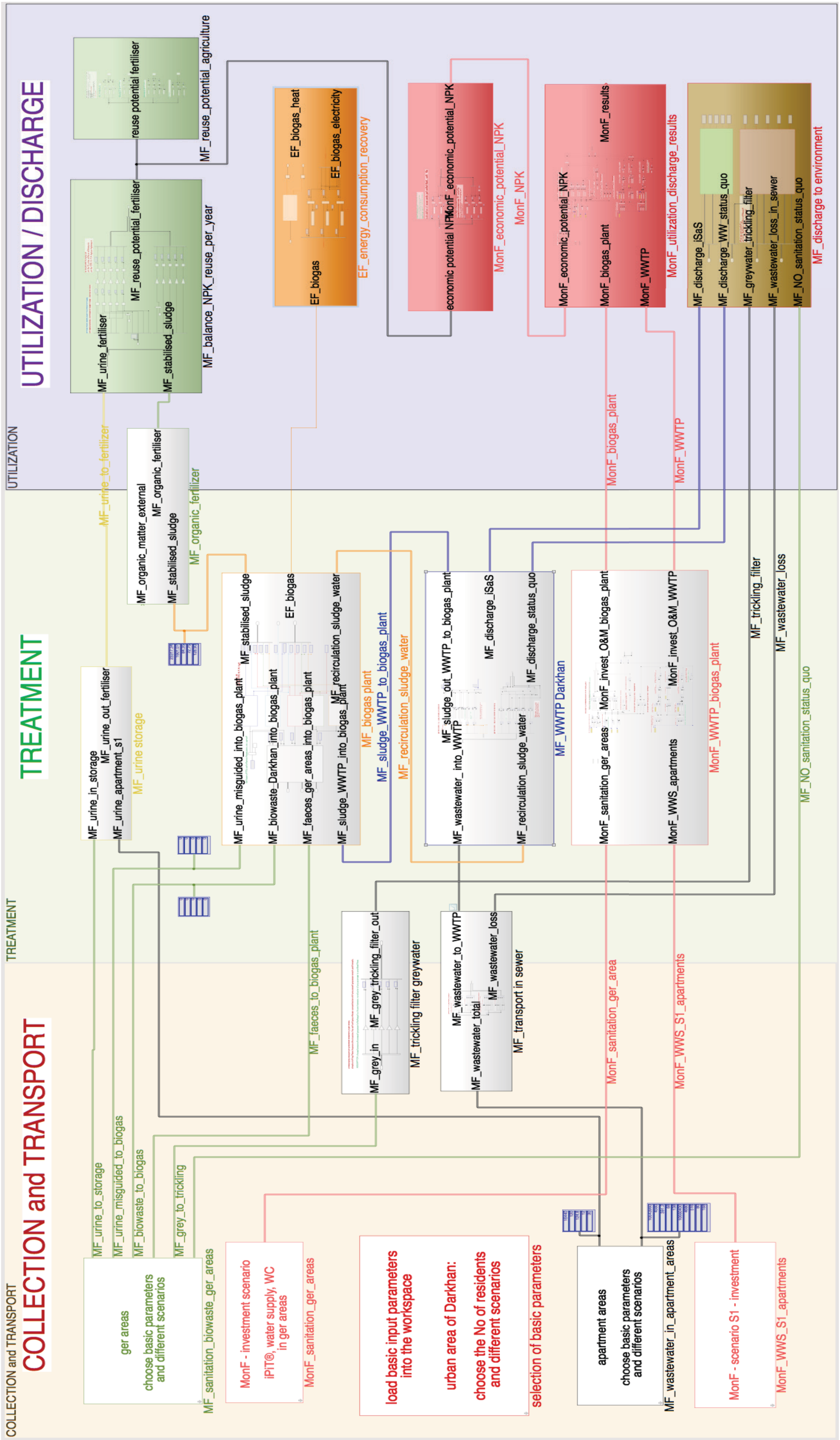


Figure 59: Overview of complete iSaS model for Darkhan built in Simulink®

D.4.2 Variations of specific parameters within the model - examples

In the model, some variations of specific parameters are built-in and can be simulated directly without changing the parameters in the xls-file. This functionality is accessed by double-clicking on one of the masked subsystems, such as “ger areas” and “apartment areas”.

Two examples are explained below: i.) the variation of the urine partition ratio in the iPiT® and ii.) the variation of the biowaste collection ratio.

D.4.2.1 Partition ratio of urine and faeces in iPiT®

In Bruski (2015) a problem with misguided urine in the iPiT® is described. Presumably a.) not all participants in the pilot project used the iPiT® correctly: urinating in standing position or b.) did not use it exclusively: urinating openly in the garden or using external toilets at work. It is stated, that the separation efficiency in reality is far below the idealised values of literature, which may be caused by less engaged users. The calculated quantity of faeces from the iPiTs was only about 25% of the characteristic literature values from Germany.

For the operation of a citywide iSaS in Darkhan, it would be crucial to improve the efficiency of the separation unit. Misguided urine disturbs the emptying frequencies and has also negative impact on the digestion process in the biogas plant. It is assumed, that the main reason for the insufficient partition ratio is wrong usage of iPiT® (Bruski, 2015, pp. 70–75).

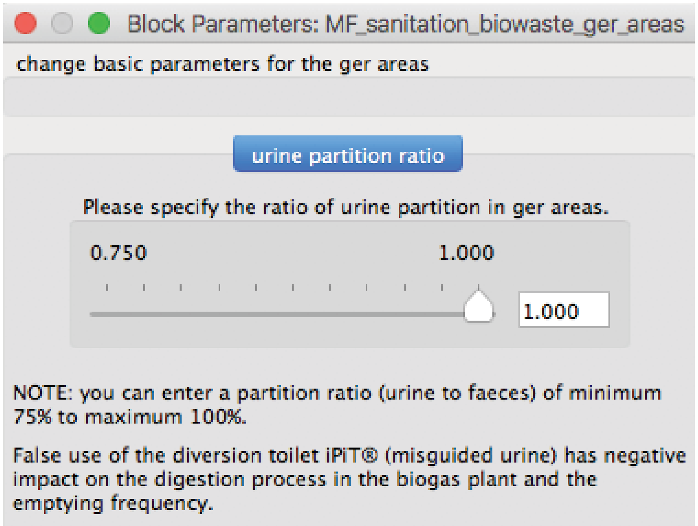


Figure 60: Variation of urine partition ratio - iPiT®

The author of this dissertation has its own iPiT® (1:1 model of the Mongolian version) in operation. This iPiT® is frequently used by guests, who are completely new to the concept of a UDDT. Personal observation proves, that a partition ratio of nearly 100% can easily be achieved with the introduced technology.

For Darkhan this would mean repeated effort to explain the correct use of iPiT®: i.) sitting on the toilet seat or ii.) consequent use of the urinals for men.

As this interesting case is a realistic scenario, it is simulated in the model and the partition ratio of iPiT®’s can be specified as between 70% - 100%. This variation influences the results of the whole simulation, for example: quantity of urine collected, number of collection tours, number of trucks, staff member, storage size and investment, area of farming land to be fertilised, economic potential of reuse.

D.4.2.2 Partition ratio of biowaste collection in Darkhan

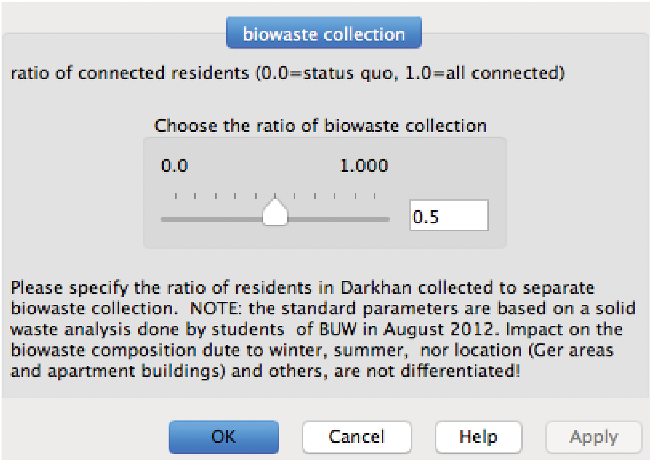


Figure 61: Variation of biowaste collection ratio

Another interesting case and not unlikely scenario is a stepwise introduction of separate collection of biowaste as it has been described in (Böhm et al., 2013).

A separate collection of biowaste can initially be introduced in the apartment areas, which are easily accessible and where installations for waste collection (collection points, bins, partly in the buildings) exist already. However, the concept of waste separation itself would be new to many citizens in Darkhan.

Further on it can be expected, that the biowaste composition is subject to strong seasonal fluctuations, in particular in the ger areas. It is known, that the quantities of biowaste are generally quite low in Mongolia compared to standard literature values. In wintertime, ashes from coal and wood fires account for a large part of the waste composition in the ger areas.

In case it is possible to initiate separate waste collection in Darkhan, alternating qualities of biowaste have to be expected, with potentially negative effects on the treatment process. Collection points for separate biowaste collection can be established in the apartment and ger areas. The collection could be combined with the prevalent transport and emptying services.

In the model the change of waste composition and quantities as well as resulting higher efforts in the treatment processes are not considered. Rather, it is assumed that the system would be well functioning when implemented and that biowaste composition remains unchanged.

D.4.3 Analysis of three different scenarios

Three different scenarios are further on described, which are implemented in the model in Simulink® as examples for variations of the sanitation system in Darkhan. The selection of different scenarios enables or disables certain subsystems in the model. The inclusion of scenarios requires a more sophisticated adjustment, as different parts of the model will be executed in the simulation.

The different scenarios are discussed by the variation of different critical parameters and further analysis of the results of the simulation, similar to a sensitivity analysis.

D.4.3.1 Scenario zero – status quo – conventional WWT system without and with iPiT® sanitation in ger areas

The fundamental scenario zero represents the status quo of the situation in Darkhan. It is the reference scenario and equally the starting point for all further adjustments. Scenario zero actually consists of two parts.

One is the real situation with the existing conventional WW system only for the apartment areas and no sanitation system for the ger areas in Darkhan. The second part of scenario zero is the imagined situation of the existing conventional WW system for the apartment areas combined with the iPiT® sanitation system for the ger areas.

The reference scenario is implemented in parallel to the iSaS-part of the model. The parallel implementation allows for a direct comparison of alternate systems with the status quo. It directly illustrates achievable changes by variations of different parameters and scenarios.

Figure 62 shows the discharge of the material-flows to the environment of the status quo (red box) and the imagined implemented iSaS (green box). The theoretical improvements can be seen in the displayed numbers (blue boxes).

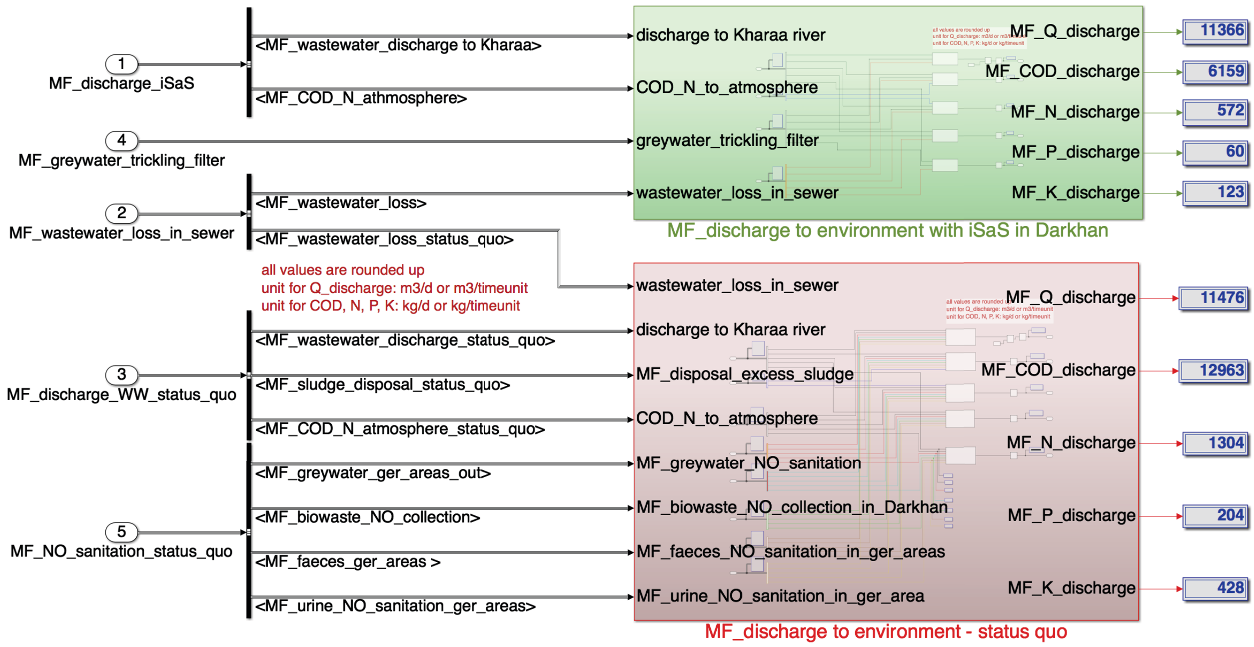


Figure 62: Scenario zero - status quo and iSaS - discharge to environment

The environmentally harmful way of discharging untreated material-flows will be significantly reduced by the implementation of iSaS. The comparison of the status quo without sanitation in ger areas as the reference scenario with the combined approach of the conventional and iSaS sanitation system reveals some interesting facts:

Results with regard to material-flows

It is not surprising that the combined iSaS approach has considerably lower negative impact on the environment. The quantities of materials-flows, which are directly discharged to the environment, are significantly lower as can be seen in Figure 62.

It is though interesting to look at the main sources for the remaining quantities of the material-flows in the combined iSaS system, which are still discharged to the environment without treatment (green box). The analysis of the source of the material-flows is summarized in Table 18.

The parameters for the simulation were set as follows: 60,000 residents ger areas, 40,000 residents apartment areas, no biowaste collection, urine partition ratio in iPiT® 100%, ratio of wastewater loss in sewer 30%.

Table 18: Sources of discharge to environment - scenario zero plus iSaS

source of material-flow	COD [kg/d]	COD % of total	N [kg/d]	N % of total	P [kg/d]	P % of total	K [kg/d]	K % of total
greywater ger areas	2820	**61%**	60	21%	30	**50%**	60	49%
wastewater loss in sewer	1404	30%	155	**53%**	24	40%	50	41%
discharge WWTP to Kharaa river	415	9%	76	26%	6	10%	12	10%
total discharge	4639	100%	292	100%	60	100%	123	100%

Table 18 presents the quantities discharged to the soil and the water bodies. The quantities of COD and N, which are degraded in the WWTP and relieved to the atmosphere, were already subtracted from the simulation results in Figure 62, because of their neutral impact on the environment. The results of the simulation show that more than 60% of COD discharged and around 50% of P discharged originates from the untreated infiltration of greywater in the ger areas. More than 50% of N discharged originates from the wastewater, which is infiltrating in an uncontrolled manner to the soil.

With these results, it is possible to define the future need for action for an improvement of the combined iSaS in Darkhan. Assuming that the WWTP is functioning well, it can be recommended to focus activities on a suitable way for greywater treatment and rehabilitate the sewer system to reduce the uncontrolled loss.

Results with regard to monetary-flows

The discussion of the economic consideration of the iSaS scenario is more diverse compared to the material-flows. First of all, it has to be assumed that some technical issues regarding the way to empty the urine and faeces containers in winter are solved. The winter solution presented in Chapter C.2.3.3 is not feasible for a permanent up-scaled operation of the iSaS. Secondly all components and mode of operation have to be analysed with regard to investment costs, operation and maintenance. For most parts of the iPiT® sanitation system in the ger areas data is available, though the figures have to be seen critical and were therefore verified by comparing them with prices from Germany. For new constructions with unknown investment costs, the prices were estimated based on comparable constructions.

Example – urine storage pond:
A suitable urine storage pond for the Darkhan case has not yet been developed. The investment costs are estimated based on the following assumptions: 60,000 people in ger areas produce roughly 30,000m^3 urine per year. The ponds have to be located close to the area of urine application, which in this case are the three main agricultural areas. The distances to these areas are used in the calculation for the operation of the transport system. As urine will be used as fertilizer and can only be applied in spring and autumn, it is necessary to provide a storage capacity for half of the total quantity. In this case 15,000 m^3 at three locations or at each location 5000 m^3. Excavation is quite cheap in Mongolia and estimated to 105,000,000 MNT or approximately 42,000 € based on actual Mongolian prices (5,000 MNT/m^3 for excavation, 2,000 MNT/m^3 for removal).

For each location (5,000 m^3) a 5 m deep storage pond, side slope 2 x 45°, 100 m long, is estimated to a bottom surface of approximately 2000 m^2. At the three locations, this sums up to 6,000 m^2 of bottom sealing *(landfill liner without asphalt and leachate drainage)* and an equal area of 6,000 m^2-cover of the storage pond. The cover should be removable for winter and summer purposes. The combined estimated price according to German prices from 05.2016 (bottom sealing = 58 €/m^2 and cover = 32 €/m^2) = 90 €/m^2. This results in a lump sum price for storage capacity of (3*180,000€) + 42,000 € = **582,000 €** for the scenarios discussed here.

All the assumptions for this and other constructions or modes of operation are summarized in the MS Excel® file *"iSaS_variables.xlsx"*. Baseline values of the assumption of specific values and all scenarios are stored in the column *"baseline value prior to variation".*

If possible the prices have been verified with actual German prices. In case of doubts, unfavourable conditions for the iSaS system and more favourable conditions for the conventional sewage system have been chosen respectively. Although it has been attempted to include the most realistic costs, many of the estimated prices and assumptions remain debatable. However, the following results of the variations of the most critical variables in the iSaS model show an important and clear trend for the future development of a sanitation system for Darkhan (see Table 19).

The following parameters of the **iPiT® sanitation system** have been varied on the basis of 60,000 residents in the ger areas:

a) economic lifetime iSaS (least common multiple): MonF_lifeT_iSaS_lcm
b) O&M costs in % of total investment iPiT®: MonF_OM_iPiT
c) investment costs iPiT®: MonF_invest_iPiT
d) economic lifetime iPiT®: MonF_lifeT_iPiT
e) cost recovery through service fee paid by residents: MonF_cost_recovery_ger

Table 19: Variation of critical variables - iSaS with iPiT® in ger areas

economic variation - iSaS with iPiT® in ger areas (60,000 residents)					
variations	**1** (baseline)	**2** (lifetime iPiT® enhanced)	**3** (maintenance iPiT® high)	**4** (mass production iPiT®)	**5** (willingness-to-pay high)
adjusted values MonF_lifeT_iSaS_lcm: **a)** MonF_OM_iPiT: **b)** MonF_invest_iPiT: **c)** MonF_lifeT_iPiT: **d)** MonF_cost_recovery_ger_HH: **e)**[1)]	a) **30a** b) **1.5%** c) **710€** d) **10a** e) **40€**	a) **60a** b) 1.5% c) 710€ d) **12a** e) 40€	a) 60a b) **4.0%** c) 710€ d) 12a e) 40€	a) 60a b) **1.5%** c) **450€** d) 12a e) 40€	a) 60a b) 1.5% c) 450€ d) 12a e) **70€**
total investment costs and re-invest over specified lifetime	25,658,310 €	42,420,300 €	42,420,300 €	29,030,340 €	29,030,340 €
investment costs annualised: MonF_invest_**iSaS**_ger_area	855,277 €	707,005 €	707,005 €	483,839 €	483,839 €
O & M costs annualised: MonF_OM_**iSaS**_ger_area	344,424 €	344,424 €	534,424 €	305,424 €	305,424 €
cost present value iPiT® / iSaS	1,199,701 €	1,051,429 €	1,241,429 €	789,263 €	789,263 €
*potential cost recovery rate iPiT® sanitation (**excluding** treatment costs)*	*55%*	*63%*	*53%*	*84%*	***144%***
total annual costs iSaS per PE (related to 60,000 PE)	**20 €**	**17.5 €**	**20.7 €**	**13.1 €**	13.1 €
1) number of residents per HH = 3.7 person (PE) according to (National Statistical Office of Mongolia, 2013)					

The results of the variations 4 and 5 in Table 19 show that reduced investment costs and an enhanced willingness-to-pay have the most significant impact on the affordability of the iPiT® sanitation system. Further on the results of the economic variation of the iPiT® sanitation system are compared with the costs for a conventional sewage system for all ger areas in Darkhan.

The **conventional wastewater system** for ger areas is calculated on the basis of prices derived from a tender process with 4 Mongolian construction companies, form March 2013. After evaluation of the offers, the most realistic price (7,000,000 € for bag7: IP_urb_ger_area_bag7 = 1.22 km^2) has been extrapolated to all ger areas in Darkhan (see Table 20).

Table 20: Investment costs in WWS for all ger areas in Darkhan

INVESTMENT costs	**calculation with specific values**	**assumption based on reference values**
total area ger areas in Darkhan: IP_urb_ger_area	12.53 km^2	specific prices from Germany (lower burial depth): i.) 23 Million € / 10,000PE = 138 Million € / 60,000 PE in ger areas Darkhan according to (Halbach, 2003, p. 16) ii.) 400 – 550 €/m based on medium diameters (ND 250-400) of sewage pipe, or 93.2 – 128.2 Million € (**without** road construction) (oral information from a German engineering consultant, 2016)
investment cost area per km^2: MonF_invest_WWS_ger_per_area	5,737,705 €/km^2	
total investment in a conventional WWS for ger areas in Darkhan	**71,893,444 €**	
total road network Ger areas: IP_infra_road_ger_total	233.1 km	it is assumed, that the length of road network = length of public sewage canals. the house connection lines, manholes etc. are included in the price.
sewage canal in € / m	308.5 €/m	

The total investment costs for a WWS in all ger areas in Darkhan sums up to almost 72 Million € or approximately 310 €/m network (including house connections). It has to be stated that the specific values include a fair amount of uncertainty, in particular as different diameters were not specifically indicated and household connections can vary significantly. The comparison with German specific values, however, confirms that the calculation is within a realistic range.

The following parameters of the **conventional wastewater system** have been varied on the basis of 60,000 residents in the ger areas:

a) economic lifetime WWS (least common multiple): MonF_lifeT_WWS_lcm
b) O&M costs in % of total investment WWS: MonF_OM_WWS
c) Investment into a drinking water supply system included: DWSS_included
d) ratio of total investment costs WWS into DWSS: DWSS_ratio
e) investment into a heated toilet house or bathroom included: MonF_invest_house_toilet
f) cost recovery through service fee paid by residents: MonF_cost_recovery_ger

Table 21: Variation of critical variables – conventional WWS in ger areas

economic variation – conventional WWS in ger areas (60,000 residents)				
variations	**1** (baseline, only WWS)	**2** (including DW supply system)	**3** (including heated bathroom)	**4** (willingness-to-pay high)
adjusted values MonF_lifeT_WWS_lcm: **a)** MonF_OM_WWS: **b)** DWSS_included: **c)** DWSS_ratio: **d)** MonF_invest_house_toilet: **e)** MonF_cost_recovery_ger_HH: **f)**[1)]	a) **60a** b) **1.0%** c) **NO** d) **20%** e) **NO** f) **40€**	a) 60a b) 1.0% c) **YES** d) 20% e) NO f) 40€	a) 60a b) 1.0% c) YES d) 20% e) **YES** f) 40€	a) 60a b) 1.0% c) YES d) 20% e) YES f) **70€**
total investment costs and re-invest over specified lifetime	79,082,760 €	94,899,360 €	117,699,360 €	117,699,360 €
investment costs annualised: MonF_invest_**WWS**_ger_area	1,318,046 €	1,581,656 €	1,961,656 €	1,961,656 €
O & M costs annualised: MonF_OM_**WWS**_ger_area	718,934 €	862,721 €	862,721 €	862,721 €
cost present value WWS	2,036,980 €	2,444,377 €	2,824,377 €	2,824,377 €
*potential cost recovery rate WWS in ger area (**excluding** treatment costs)*	*32%*	*27%*	*23%*	***40%***
total annual costs WWS per PE (related to 60,000 PE)	**34 €**	**40.7 €**	**47 €**	47 €
[1)] number of residents per HH = 3.7 person (PE) according to (National Statistical Office of Mongolia, 2013)				

Variation 1 and 2 still lack the water supply system and the heated bathroom in each khashaa, and are incomplete. Yet the variations are important for a better understanding of the situation, and a reason, why the two systems (iSaS and WWS) are not directly comparable. The drinking water supply system is estimated with additional 20% of the WWS investment costs and a heated bathroom is assumed to cost 1,900 €/khashaa. The values were favourably chosen for the conventional system.

Variation 3 shows the required minimum for an implementation of a conventional sewage system in ger areas. Even with an enhanced willingness-to-pay, as presented in variation 4, the cost recovery rate is still far below half of the calculated cost present value of the WWS.

D.4.3.2 Scenario one – iSaS and urine diversion in apartment blocks

Scenario one describes the gradual implementation of urine separation in the existing apartment blocks by installing waterless urinals for men as a well-proven technology.

The idea behind scenario one promises to have some benefits for the efficiency of the sanitation system in Darkhan:

- reduction of water consumption,
- reduction of nutrient load (in particular N) to the WWTP, resulting in
- reduced operational costs,
- improved reuse possibilities and value added.

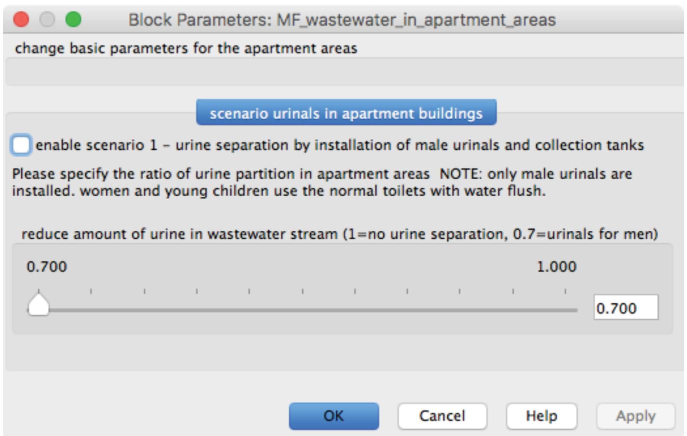


Figure 63: Selection of scenario 1 - urine diversion in apartments

Waterless urinals are technically relatively easy to install in the apartment buildings. Urine can be stored in underground tanks and directly used in agriculture.

The technology can be easily introduced to the people and problems with acceptance will most likely not occur. It is assumed, that only adolescent and grown up men are using the waterless-urinals.

The maximum partition ratio of separately collected urine is therefore set to 30% of the total amount.

70% of the urine will remain a part-flow of the regular wastewater and will be discharged to the WWTP for further treatment.

For this scenario, the technical solution requires a storage tank well below ground and 200 m connection pipelines including ventilation. The tank size is chosen to be suitable for the connection of three standard apartment blocks (one standard block has two entrances) and an emptying frequency of two times per year with rented pumping trucks. The urine can be applied directly or intermediately stored in the urine storage ponds. Additional volume is not required.

Scenario 1 can be enabled and disabled in the model and the urine partition ratio can be chosen. Additionally, it can be specified if the operator of the iSaS has to pay for the investment costs for waterless urinals in the apartments or not. Further on scenario zero **with** sanitation in ger areas (iSaS Darkhan) is compared with scenario 1 "*urine diversion in apartments".* Furthermore, the collection of biowaste in Darkhan is considered in the simulation of the material-flows.

Results with regard to material-flows

The following Table 22 summarizes the full potential of resource recovery in the city of Darkhan under the given assumptions, whereby the parameter Q expresses the amount of material that needs to be collected, transported, and reused *after* the treatment processes. The increase of quantities is put in reference to the iSaS / iPiT® scenario and accumulated.

Table 22: Potential increase of resource recovery by urine separation in apartments and biowaste collection

MF potential – scenario 1 urine separation in apartment areas (40,000 residents) **and biowaste collection** (100,000 residents)						
MF	**1** (**iSaS baseline**, S1 disabled)	**2** (**S1 enabled**, 30% separation)		**3** (S1 enabled, **biowaste** collection 100%)		*total increase in reference to baseline*
potential			*increase*		*increase*	
Q [m^3]	38,554.0	44,547.0	*16%*	44,748	*1%*	*16%*
COD [Mg]	808.3	847.8	*5%*	995.3	*18%*	*23%*
N [Mg]	262.0	304.3	*16%*	307.6	*1%*	*17%*
P [Mg]	51.3	52.9	*3%*	54.1	*2%*	*5%*
K [Mg]	108.8	112.8	*4%*	115.5	*2%*	*6%*

The total amount of MF, which is separated from the regular wastewater stream and therefore not entering the treatment processes in the WWTP, sums up to Q 6,005 m^3/a, COD 43.8 Mg/a, N 45.6 Mg/a, P 4.4 Mg/a, K 11 Mg/a.

Results with regard to monetary-flows

The costs in Scenario 1 are calculated in a first step without the necessary installation of the waterless urinals in the bathrooms of the apartments (variation 1), and in the second step by including the costs for the waterless urinals (variation 2). The annual costs for each PE are calculated as well as the total economic potential of resource recovery from NPK. The results are summarised in Table 23.

Compared to the baseline scenario iSaS with iPiT® the increase of investment is 8% (without waterless urinals, and 27% with urinal installation). The increase of 8% investment is lower compared to the increase of roughly 13% of the economic potential of resource recovery NPK. But even if it would be possible to access the full economic potential of resource recovery *and* the residents would pay for the high installation costs in their apartments, this scenario could economically not be justified, as long as other cost recovery measures cannot be discovered. According to (Dockhorn, 2007, p. 51) around 10.4% and 6.9% of the total annual costs can be related to the treatment of N and P in the WWTP, respectively. The specific values were gained by examining the case of a WWTP for 350,000 PE in Germany.

In the Darkhan case the total amount of NPK entering the treatment plant is reduced by 24% (N), 15% P, and 18% K, respectively, in scenario 1. This would lead to an estimated reduction of the treatment cost of 2.5% (N) + 1% (P) = 3.5% at the WWTP Darkhan. Depending on the design of the treatment plant, the economic cost recovery would be in a range of 17.500 € to 35.000 €.

Table 23: Economic consideration of scenario urine separation in apartments

economic variation – scenario 1 – urine separation in apartment areas (40,000 residents)			
variation NOTE: the iPiT® / iSaS baseline corresponds to Table 19	(**iPiT® / iSaS baseline**, S1 disabled)	**1** (**S1 enabled**, 30% separation, waterless urinals **not included**)	**2** (S1 enabled 30%, waterless urinals **included**
adjusted values operator_pays: **a)**	please refer to Table 19	a) **NO**	a) **YES**
total investment costs and re-invest over specified lifetime	42,420,300 €	1,693,200 €	4,740,960 €
investment costs annualised	707,005 €	56,440 €	257,632 €
O & M costs annualised	344,424 €	25,128 €	25,128 €
cost present value	1,051,429 €	81,568 €	282,760 €
total annual costs S1 per PE (*40,000* I **100,000**)		*2.0 €* I **0.8 €**	*7.1 €* I **2.8 €**
*economic potential of resource recovery NPK by scenario S1 in apartment area (**excluding** treatment costs)*	-	*55,848 €*	*55,848 €*
[1)] number of residents per HH = 3.7 person (PE) according to (National Statistical Office of Mongolia, 2013)			

It cannot be expected that the residents are willing to pay for the high installation costs for a waterless urinal without a clear economic benefit. But in newly built apartment houses the installation of waterless urinals can be considered as neutral for the cost calculation of the sanitation system and the fee for sanitation services.

The additional installation costs and the O&M for the separate collection of urine in newly built apartment blocks have the potential to be neutral or positive depending on the circumstances. The lower water consumption allows for more cost-effective sewage systems and even the possibility to install decentralised blackwater treatment later. The new centralised treatment facilities, as replacement for the existing WWTP, can be built smaller in size and the O&M costs can be reduced. The assessment of this scenario 1 proves to be a suitable option for the future development of sanitation services in Mongolia.

D.4.3.3 Scenario two – economic potential of resource recovery and rising energy prices

The rise of energy prices is a scenario, which is very likely to happen. It is assumed that is has strong influence on the cost-effectiveness of the transport system of the iSaS in ger areas, but also on the treatment processes and the economic potential of resource recovery from NPK.

Rising energy prices also influence all production processes and will therefore influence all other costs as well, not only the costs for the transport service. In the model, it is possible to identify the influence of single parameters on the whole system. For this purpose, the costs for fuel are changed from the baseline scenario of 0.806 €/L to a 10-fold price of 8.06 €/L. The influence on the O&M costs is displayed in the following Figure 64.

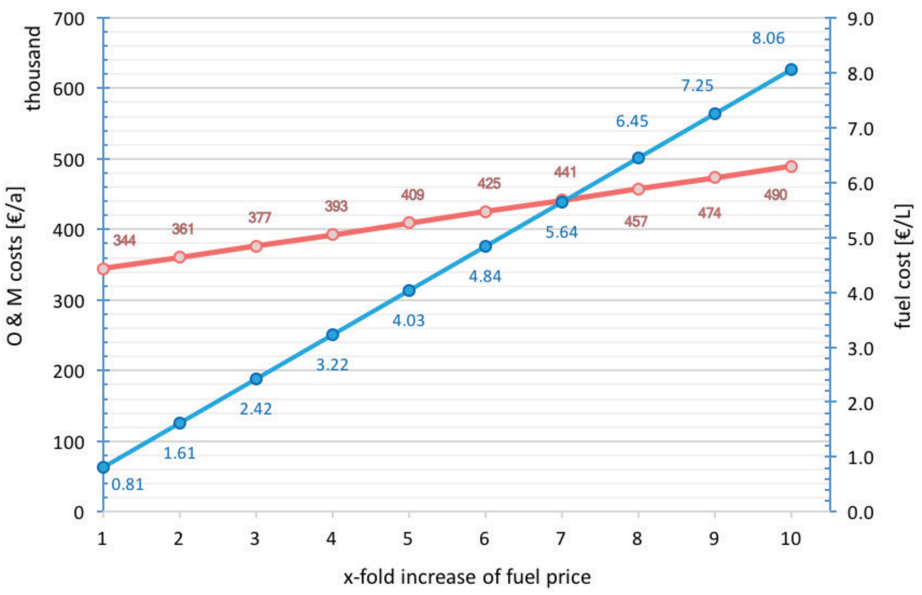


Figure 64: Increase of fuel price and influence on annual O&M costs

The results show, that the influence of the fuel costs on the overall development of the annual O&M costs is rather small. Even a ten-fold increase of the fuel-price would only increase the O&M costs by 42%.

The affordability ratio for the transport system based on the reference baseline **variation 1**, as shown in Table 19, will only decline from 55% to 49% through a fuel price increase to 8.06 €/L. The above discussed scenarios show a much higher influence of the investment costs on the cost-effectiveness of the system. Please refer to Table 19 and Table 21.

Results with regard to material-flows

High energy prices also influence the development of the world market prices for fertiliser. For this reason, it is obvious to have a closer look at the development of the economic potential of resource recovery in Darkhan. For this consideration, different variations of parameters have been examined (see Table 24). The variations 4 and 5 actually simulate the high price fluctuations on the world market for fertiliser in 2007 and 2008 (see Figure 51). The potential price for N has been *doubled*, and the potential price for P has been *tripled* in reference to the baseline scenario.

The following parameters of the **iSaS without and with urine separation in apartment areas and biowaste collection** have been varied on the basis of 60,000 residents in the ger areas and 40,000 residents in apartment areas respectively:

a) specific potential value of N: MonF_N
b) specific potential value of N: MonF_P
c) specific potential value of N: MonF_K
d) biowaste collection enabled: ratio_biowaste_collection
e) urine separation in apartment areas (scenario 1) enabled: scenario_1

Table 24: Variation of critical variables – economic potential of recovery of NPK in iSaS

variation of recovery quantities and specific potential prices for NPK					
variations	**1** (baseline)	**2** (biowaste collection enabled)	**3** (urine separation S1)	**4** (price scenario fertiliser 2007)	**5** (high prices, total recovery)
adjusted values MonF_N: **a)** MonF_P: **b)** MonF_K: **c)** ratio_biowaste_collection: **d)** scenario_1: **e)**	a) **0.89 €/kg** b) **1.81 €/kg** c) **0.67€/kg** d) **NO** (0%) e) **NO** (0%)	a) 0.89 €/kg b) 1.81 €/kg c) 0.67€/kg d) **YES** (100%) e) NO (0%)	a) 0.89 €/kg b) 1.81 €/kg c) 0.67€/kg d) YES e) **YES** (70%)	a) **1.78 €/kg** b) **5.43 €/kg** c) **0.67€/kg** d) **NO** e) **NO**	a) 1.78 €/kg b) 5.43 €/kg c) 0.67€/kg d) **YES** e) **YES** (70%)
annual economic potential N:	233,136 €	233,004 €	273,709 €	466,271 €	547,419 €
annual economic potential P:	92,777 €	95,003 €	97,921 €	278,331 €	293,763 €
annual economic potential K:	72,893 €	74,706 €	77,407 €	72,893 €	77,408 €
total economic potential NPK	**398,806 €**	**405,713 €**	**449,037 €**	**817,495 €**	**918,590 €**
economic potential NPK / PE / a	*4 €*	*4.1 €*	*4.5 €*	*8.2 €*	*9.2 €*

This consideration shows that the influence of a significantly rising fuel price is rather low compared to the rise of the economic potential of NPK by high, but realistic world market fluctuations.

D.4.3.4 Investment and O&M of a new WWTP with biogas plant

In all scenarios described here, the consideration of a new WWTP with biogas plant must be added. The number of residents is set equal with the design value PE, as in this work industrial wastewater is not considered in the material-flows and wastewater streams. Regardless of the chosen sanitation system in the ger areas, the new treatment facilities have to be built for 100,000 PE in Darkhan.

The treatment capacities and technical design of the different components of the WWTP with biogas plant for co-digestion are depending on the connected sanitation technology. For a conventional sewage system, the WWTP will have a regular activated sludge tank and most likely a digester for stabilisation. For the combined iSaS with iPiT® in ger areas and sewage system in apartment areas, the activated sludge tank will be significantly smaller, the digester bigger and an acceptance station for bin emptying, cleaning, and sludge conditioning has to be built. There is no reliable reference data available for the last-mentioned version of the WWTP. Initial price evaluations done by the author indicate that the technical components of such a facility are possibly more affordable compared to a regular WWTP. However, by assuming unfavourable conditions, the investment and O&M costs are considered as an internal shift of money in the design of the wastewater treatment facility. The alternative solution is considered as equally pricey as a regular WWTP.

Therefore, the estimation of the treatment facility is based on specific prices from Germany, which are available for a conventional WWTP with digester and N and P elimination. A specific investment price for a WWTP with 100,000 PE of 300 €/PE and an economic lifetime of 60 years have been assumed for the calculation of the annualised investment costs.

The estimation of the maintenance and material costs is based on German values (0.6% and 0.5% of the total investment costs, respectively). The annual costs for staff are assumed with a local price level. Effluent discharge fee currently does not exist in Mongolia and costs for sludge disposal are not included, because of the cost recovery potential. The electricity demand of the WWTP (25 kWh/PE/a) is slightly increased in comparison to the German specific value (25 kWh/PE/a) and calculated with the local Mongolian price for electricity per kWh (0.06 €/kWh). The summary and result of the calculation is described in Table 25.

Table 25: Additional annual costs for WWTP and biogas plant for 100,000 PE

INVESTMENT costs	**specific**	**result**	**assumption based on reference values**
investment / PE	300 €/PE		oral information Mongolia and specific prices from Germany:
total investment WWTP		30,000,000 €	i.) 260 €/PE (Halbach, 2003, p. 52),
lifetime in a	60 a		ii.) 300 €/PE – 500 €/PE based on WWTP size (oral information, 2016)
annualized investment costs		**500,000 €/a**	
O&M costs	**specific**	**result**	**assumption based on reference values**
electricity costs	0.06 €/kWh		official data from Mongolia, 2016
electricity demand WWTP	25 kWh/PE/a	150,000 €/a	20 kWh/PE/a for a conventional WWTP 100,000 PE according to (Halbach, 2003, p. 71)
maintenance	0.60%	180,000 €/a	0.6% of total investment (Halbach, 2003, p. 75)
material costs	0.50%	150,000 €/a	0.5% of total investment (Halbach, 2003, p. 75)
staff		20,000 €/a	own data evaluation
sludge disposal		-	not regarded, potential for cost recovery
effluent discharge fee		-	not existing
annualized O&M costs		**500,000 €/a**	
cost present value WWTP		**1,000,000 €/a**	
total annual costs WWTP per PE		**10 €/PE/a**	

Allocating the **total annual costs** to the residents, results in a further 10€/PE/a, which has to be added to the economic discussions above.

Currently (2016) in Mongolia the price for electricity is very low with 0.06 €/kWh. The country is capable to keep its electricity prices on a low level as it has significant resources of brown and black coal for the production of electrical energy. A fourfold increase of the electricity price results in an increase of 5 €/PE/a to 15 €/PE/a of the total annual costs for the conventional design of the WWTP.

In a combined iSaS with the iPiT® sanitation in ger areas it is possible to partially compensate the need for and rise of electricity prices in the treatment process, respectively. By applying the results of (Bruski, 2015, pp. 104, 114) the potential recovery of electricity from the digestion of separately collected faeces is approximately 7.5 kWh/PE/a. If the material-flows faeces and urine of the 60,000 residents in ger areas (in the Darkhan case) are not included in the regular wastewater stream, the total energy demand of the new treatment facility (smaller pumps, smaller aerobic sludge tank) will be significantly lower than the above specified 25 kWh/PE/a. It is estimated to be in a range of 5 – 10 kWh/PE/a. This would reduce the total electricity costs of 150,000 €/a to 30,000 - 60,000 €/a (or 0.3 € - 0.6 €/PE/a) at current price level of 0.06 €/kWh.

A detailed consideration of the new treatment facility is not yet included in the iSaS model in Simulink®. More detailed data about the energy needs can only be gained by a preliminary design of the process chain with the new technical components. Further research is recommended for a detailed analysis of the energy needs of the new treatment facility with big digester units. At the current level of knowledge, the influence of energy efficiency of the new treatment facilities on the cost-effectiveness of the whole system is considered to be much less significant, compared to the investment costs and other O&M costs.

D.4.3.5 Potential for cost recovery based on willingness-to-pay

The following Table 26 and Table 27 summarize the results described above and give an indication of the affordability of a new sanitation system for the ger areas in Darkhan under current conditions and the assumed baseline scenarios.

Table 26: Potential cost recovery rate iSaS with iPiT® in ger areas

potential cost recovery rate without & with resource recovery NPK - iSaS with iPiT® in ger areas					
variations as described in Table 19	**1** (baseline)	**2** (lifetime iPiT® enhanced)	**3** (maintenance iPiT® high)	**4** (iPiT® mass production)	**5** (willingness-to-pay high)
willingness-to-pay in €/PE	11 €	11 €	11 €	11 €	19 €
total annual costs iSaS per PE	*20 €*	*17.5 €*	*20.7 €*	*13.1 €*	*13.1 €*
total annual costs WWTP per PE ***with the potential to be lower***	*10 €*	*10 €*	*10 €*	*10 €*	*10 €*
total annual costs per PE	30 €	27.5 €	30.7 €	23.1 €	23.1 €
potential cost recovery rate: - **without** NPK resource recovery	**37 %**	**40 %**	**36 %**	**48 %**	**82 %**
- **with** NPK resource recovery, **variation 1**, Table 24: **4 € / PE / a**	**42 %**	**47 %**	**41 %**	**58 %**	**99 %**

The two completely different sanitations solutions are technically not directly comparable. However, it becomes clear, that only the iSaS with iPiT® has the potential to be an affordable solution for Darkhan.

Table 27: Potential cost recovery rate - conventional WWS in ger areas

potential cost recovery rate without and with resource recovery NPK – conventional WWS				
variations as described in Table 21	**1** (baseline, only WWS)	**2** (incl. DW supply system)	**3** (incl. heated bathroom)	**4** (willingness-to-pay high)
willingness-to-pay in €/PE	11 €	11 €	11 €	19 €
total annual costs WWS per PE	*34 €*	*40.7 €*	*47 €*	*47 €*
total annual costs WWTP per PE	*10 €*	*10 €*	*10 €*	*10 €*
total annual costs per PE	44 €	50.7 €	57 €	57 €
potential cost recovery rate: - **without** NPK resource recovery	**25%**	**22%**	**19%**	**33%**
- **with** NPK resource recovery from sewage sludge: **1.8 € / PE / a**	**26%**	**22%**	**20%**	**34%**

Under current conditions a conventional sewage system does not have the potential to come even close to a range of affordability. It is recommended to put more effort into developing the iSaS for ger areas and look for possibilities to use the economic potential of resource recovery in Darkhan.

D.5 Conclusion

The development of a model for combined sanitation systems, which are based on the principles of iSaS, has been demonstrated in this chapter. The model includes the ability to quantify resources of material-flows, energy and costs in a combined way. Beside this basic functionality, the model supports the assessment of the impact of varying parameters. This can be essential for decision-making and for the definition of a future need for action.

Functionalities of the model and used software

In order to be able to deliver such functionalities, the model was designed to describe the impact of the sanitation system on the environment and equally consider the economic impact over the planned economic lifetime. The revelation of hidden potentials by the value-added reuse of nutrients (and other content of the material-flows) can positively contribute to the sustainable implementation and operation of a sanitation system.

Such demands result in a model with a high level of complexity, which is difficult to control. Visualisation, structuring and rearranging, crosschecking, and extension become very important in the development process and the application of the model respectively. Therefore, the model is built upon a combined usage of the software products MATLAB®, Simulink®, and MS Excel®.

The spreadsheet software allows for a good organisation of basic input parameters, as well as the definition of assumptions and specifications of data sources. The possibility to change input parameters is essential for the adaption and extension of the model. For this purpose, a nomenclature for the input parameters has been developed in this dissertation.

The visualisation and implementation of the model is done in Simulink®, which is a professional and very capable programming environment for model-based simulation. The software is commonly used by many scientists and engineers at many research institutions and companies worldwide. Yet, as it is commercial, and complex software, it may not be accessible for many planners in developing countries.

The software-based model is transparent and clearly designed, yet as realistic and comprehensive as necessary to describe the chosen scenarios.

Modelling the Darkhan case

The Darkhan case is used as an example to examine the potential of such a model for scientific purposes as well as its possible practicality. The combined consideration of material-flows, energy-flows and monetary-flows in one model, is uncommon. For the development of the model, the Darkhan case is particularly suitable due to its limitations, which are caused by the clearly split urban structures and the extreme climate.

Both limitations together allow only for a limited number of technical solutions and system variations, and focus the development work on the essential functionalities of the software-based iSaS model. Yet, the model includes the functionality to simulate the impacts of variable parameters, such as energy prices, changing demography, costs and others. Different scenarios are pre-defined and further scenarios can be added.

Application, adjustment and extension – shortcomings and benefits

The software offers a variety of tools to display and analyse the results within the model, or export the data for further evaluation, respectively. Data can be logged at any point and at intermediate steps within the model, which is a significant benefit over other software solutions.

Fine-tuning of the input parameters and their corresponding values is necessary, as the Darkhan model still includes many assumptions. Preferably data from the local project should be used, as long as the data quality is sufficient. The verification of the basic input parameters is also the simplest way of adjusting the model, not only to the case of Darkhan, but to other locations as well.

The model is organised in systems and subsystems, which are interconnected by single signals or signal buses. Subsystems represent levels of the model, and with descending order they display an increasing grade of detail.

One of the major shortcomings of the model is the fact that many assumptions had to be taken. On the other hand, many simplifications had to be made. One of the most important (and not realistic) simplifications is the determination that the modelled treatment processes would always be well functioning. Therefore, in most of its parts, the models' behaviour remains static. Results of the model must be interpreted and applied wisely, as has been shown in the introduction of the different scenarios above.

The next steps for extension of the model are the inclusion of additional treatment processes and the refinement of the economic calculations. Identification, implementation and testing of additional suitable scenarios are further extension steps.

Multiple users (*or developers*) can share the development work. The system and subsystem structure allows each developer to focus on different areas and tasks within the model. The possibility to organise this development work in a team of developers is an advantage of the used software Simulink®.

The model presented here is a **good starting point** for the future development of a software-based simulation tool for iSaS. It proves the possibility to combine technical and economic considerations according to iSaS and it delivers results, which can already **support the understanding of interconnected processes** in a sanitation system.

Statements that can be derived from the simulation are already **suitable to support decision-making**. The application of the model to the Darkhan case for instance, shows that **a conventional sewage system for ger areas cannot be financed** under current conditions. The analysis of the data helps to identify focal points of future development steps.

Extended functionalities and adaption to different locations can be built into the model according to the particular needs of a user.

E Review and outlook

In this chapter, the iSaS principles will be revised briefly and critically. Can the theory of iSaS actually contribute to improve the situation and support the sustainable development of sanitation systems? Is a software-based model, as described here, capable to support decision making in the future? What can realistically be improved now, what can maybe be improved later, which changes cannot be expected to happen soon? In this context, the application of iSaS model is briefly discussed.

E.1 Discussing the application of the iSaS principles

The principles of iSaS have been described in Chapter B and a definition of iSaS has been elaborated. In this work, it was possible to show that some problems could potentially be solved.

However, a fundamental change of paradigm in the development of infrastructure systems is still not in sight. Planners and decision makers have the habit to trust commonly accepted standards more, even if it is proved that conventional solutions would not work well in the particular context.

E.1.1 Limitations to the implementation of iSaS

It is demanding to consider new approaches. The way of thinking in traditional solutions is also structurally supported, as many development and research projects focus on the short-term project outcome, and do not consider realistic periods, which would have to be much longer than the usual 3-year project timeline. Furthermore, governmental initiatives rely on popular measures, with a lot of media attention and lot of money involved.

For instance, in **the case of Darkhan**, the reconstruction of the WWTP has been proposed for approximately 30 million €. The residents of Darkhan would hardly benefit from such a measure, as it would only reduce the amount of contaminants released to the environment. The number of people with access to the sewage system would probably not increase through this very costly measure. On the other hand, the residents in the ger areas would still not gain access to sanitation. With a fraction of the proposed investment into a new WWTP, it would be possible to significantly improve the precarious situation in the ger areas. By up-scaling the iSaS pilot project in Darkhan, it would be possible to almost instantly raise the number of people in Darkhan with access to sanitation from 40,000 to 100,000 people (an improvement of 250%).

There is a long way ahead to reach decision-makers and their consultants, before changes can be expected. The principles of iSaS can certainly support this process.

The higher the level of diversion ←→ the deeper the level of integration

However, willingness to understand and to deal with interdependent technological and socio-economic conditions has to be present. The consideration of technology, legal framework, organisation, users, entrepreneurs, political stakeholders and so on in one approach such as iSaS, can make the development of an infrastructure system complex.

Infrastructure developers need to have a high level of general knowledge and understanding of a variety of problems from different professional fields. Good communication skills and the lust to networking are indispensable in this field. The design of an iSaS is a very creative and interdisciplinary process with the potential to experience setbacks and unexpected project outcomes. A certain level of resilience and patience is needed in such a project.

Governmental responsibilities

Many of the problems in infrastructure development are related to an unequal state of knowledge and lack of experience of planners and government officials. It is unlikely for any reader of this dissertation to be able to work in a place, where it is possible to choose the right methods, right partner, right project periods, right monitoring and right follow-up. Communication is therefore on an equal footing with technology.

Sanitation for the urban poor, remains "poor" if it does not equally have the potential to serve wealthier parts of a society, in particular as decision-makers are not interested to achieve a "*poor"* standard. This may be a hindrance as an approach such as iSaS has likely lower investment costs compared a conventional system. This combined with the higher level of transparency of iSaS, makes such an approach uninteresting for some corrupt decision-makers and donors.

E.1.2 Transferability of iSaS

No major hindrances are expected concerning the transferability of iSaS to different geographic locations, climate zones, culture, socio-economic conditions, urban structures and so on. The iSaS approach is very open and general and can easily be adapted to other local circumstances.

Also variations of technology and system components, which are strongly dependent on the project context, should be possible as can be seen in (iReBa Team, 2014). The Darkhan case with iPiT® is just an example. In other countries, the solution can require very different technological components, but the general principles of iSaS would remain the same.

E.2 Discussing the application of the iSaS model

The discussion of the development and application of the iSaS model (as described in Chapter D) at the example of the Darkhan case needs to consider the constraints, which come with the simplifications of a real situation and the assumptions that had to be taken. This is essential in order to be able to interpret the results correctly.

E.2.1 Uncertainties, assumptions and limitations

Uncertainties of available data and impact of variations

One difficulty with the model is related to uncertainties of the basic data (e.g. population figures, water consumption, economic data), which consequently leads to assumptions. The included technical assumptions are verifiable, in particular if it is possible to refer them to literature values. Technical and process correlations are well examined and predictable.

With regard to economics, the verification of the assumptions cannot be done so easily. For instance, the impact of energy prices and other resources (such as phosphorus, construction material, imported goods) on the model is significant and hard to predict. The real situation depends strongly on fluctuations in the world market and the local particular situations respectively.

Concerning the supply with oil, for instance, Mongolia is dependent on Russia. The reliability and predictability of this source is currently low due to political reasons, but the impact is significant. A stable situation is usually (and ideally) assumed for the design of an infrastructure system. The model can be used to simulate unusual events and assess their impact on the proposed system.

Dependent variables

Some specific values of variables are dependent on dimensions of treatment facilities, number of units produced, number of people connected and so on. In the model, they are included in the form of a constant value, which is a simplification of the reality.

For instance, the specific value of the variable "*unit costs for iPiT®"* is depending on production numbers. Or the specific value for *"radiation of heat from the digester"* (in the model related to a digester for 100,000 pe) depends on the process, the dimensions of the digester, and the number of connected people. Similar considerations can be made regarding specific values of the variables *"construction costs sewer"* (€/km sewer installed), or "*population density"* and so on.

The variation of the values of these variables are dependent on the dimension of treatment processes, construction costs and others, and are not considered in the model. Only some values are linearly adjustable according to the connected users. It is assumed that specific values are constant within a defined range, which in this case is fitting to the Darkhan case study.

Process assumptions and environmental impact

The model works with idealised treatment processes. It is assumed that the treatment processes work as described in textbooks: no disaster, no mismanagement, no mal-functioning would occur.

Also changes in treatment efficiencies are not built into the model. For instance, should the high water consumption in the apartments be reduced by installing water meters, the wastewater load would be higher and degradation rates would equally be higher within a certain range. This would eventually result in lower specific energy-costs (€/m^3) for the activated sludge process. Probably another specific value would have to be chosen in that case, or the correlation between load, temperature and energy costs is known and built into the model.

The use of specific values is convenient and often the only useful way to deliver quick and suitable results. But in situations with strong variations it can become unrealistic to work with specific values. The presented results have to be interpreted and applied wisely.

Indirect costs for environmental damages due to untreated disposal, or long-term costs for bad health, are not included in the model. The consideration of these **indirect environmental** and other related **societal costs** is certainly interesting in order to be able to provide more in-depth statements for decision-making. For such cases other methods are more suitable such as a LCA or an utility analysis (Hein et al., 2015).

E.2.2 Sensitivity analysis of the Darkhan case

The status quo in Darkhan without sanitation in ger areas has been used as a reference scenario for the comparison with the combined iSaS approach. Three scenarios have been developed and analysed in Chapter D.4.3. The different scenarios are discussed by the variation of critical parameters and further analysis of the results of the simulation, similar to a sensitivity analysis. The results of the model show that even in uncertain circumstances, the tendencies of the calculations are correct. This means the model is capable to deliver useful results.

The application of the iSaS model and the analysis of the results demonstrate the complexity of influences on the system. The results are useful to define the need for action for the implementation and operation of future sanitation systems in Darkhan. For instance, it is possible to give clear recommendations with regard to the affordability of a new sanitation system for the ger areas in Darkhan.

The conventional WWS and the iSaS sanitation solution with iPiT® are in many ways different and technically not directly comparable. The main result of the analysis is due to the circumstance that it was able to show that only the iSaS with iPiT® has the potential to be an affordable solution for Darkhan, and the conventional sewage system is under given conditions far from being financeable. But also, the iSaS is not automatically cost-effective and is not yet affordable and cannot be re-financed completely.

Only a **combination of the four following measures** has the potential to lead to a complete cost recovery rate of a sanitation system in Darkhan:

1. Enhance the “willingness-to-pay” and collect justifiable fees from the users of the system, for instance:
   a.) participation in covering investment costs for iPiT®, iPiT® rental, or
   b.) cross-financing from apartment areas that benefit from a more comfortable water supply system.
2. Push down the prices for investment costs of the iPiT® and the new treatment facility by
   a.) mass production of iPiT® and
   b.) optimised process design respectively.
3. Optimise the treatment process to lower O&M costs of the new treatment facility.
4. Unleash the potential of NPK resource recovery.

E.3 Conclusion and outlook

Significance of the integrated sanitation system

The need for integrated approaches is obvious in the early 21st century. In particular, for rapidly changing urban environments with an underdeveloped infrastructure, the conventional system can hardly offer affordable and flexible solutions. In rural areas, the conventional system with long sewers and central WWTP is too expensive anyway, even in countries like Germany. The sole adherence to the conventional approach is now prohibiting progress and is in many cases responsible for malfunctioning or non-existent infrastructure systems.

The integrated sanitation system, which has been described here, is tailored to the local conditions and the special situation in Mongolia. But the system can be transferred and adapted to circumstances in different countries and climate zones. In certain aspects, an iSaS requires stable socio-economic conditions and a minimum of economic development, in order to allow people to sustain the sanitation system.

These minimum requirements for iSaS have been considered during an estimation about how many of the people without access to sanitation, could actually benefit from an iSaS (Feldmann, 2013). The results show a huge potential, of an estimated 575 million people in urban and peri-urban environments, who could potentially benefit from iSaS.

E.3.1 Further development of iSaS and iPiT®

Assessing the grade of realisation of integration of iSaS

In case a sanitation system is implemented based on the principles of iSaS, it would be interesting to assess the *level* or the *realisation of integration* of the iSaS. Answering this question would be helpful to **evaluate** the definition of iSaS and make statements related to **its suitability for daily use**. By surveying the level of integration, the principles of iSaS can be revised and either be rejected or further developed.

Further on if one would be able to define the level of integration, it will become possible to evaluate and compare different sanitation systems. It would also be important to analyse if the principles of iSaS are actually in correlation with a well-functioning sanitation system or not.

Promoting the idea

In case the answer is positive, **iSaS** could be further developed **as a predicate** or rating system **for sanitation** systems. The trademark **iPiT®** could be used to **promote** the ideas of iSaS by marketing it as synonym for a well-functioning **modern form of sanitation**.

Technology ready-for-market

One major downside of alternative systems is the lack of ready-for-market technology. Compared to conventional systems, the available technical options did not have the time to mature. Substantial development work is still needed to achieve the same high level of reliability, acceptance and marketability of alternative, source separation technologies.

The chain of technology and processes consisting of *user interface* (toilet), *collection* (e.g. container, pits), *transport* (trucks, horse carts, vacuum sewers), *storage*, and *treatment*, **has to work seamlessly together.** Research and engagement of the private sector is needed to solve this problem.

E.3.2 Suggestions for further development of the iSaS model

The model presented here can be understood as a starting point for the further design of a software-based simulation model for iSaS. It needs improvement and a deeper, more detailed development to extend the model beyond the case of Mongolia and ensure a broader usability in different setups.

Suggestions for the further evolution of the model are:

- Inclusion of further parameters (e.g. TOC, water content, TS, TVS) to enable the simulation of other types of material-flows, such as organic wastes from animals or food industries, ideally selectable.
- Modelling of other collection and treatment technologies, such as vacuum sewers, composting, dry fermentation, constructed wetlands, trickling filters, struvite precipitation reactor and others, ideally selectable in form of enabled subsystems or separate models.
- Enhance variations of parameters and selection of scenarios directly in the model.
- Refine the financial calculation and include a fully detailed CCC or a similar suitable method.
- Refinement of the user interface.
- Enhancement of the output and analysis methods of the results of the calculation, including advanced visualisation.
- Publication of an accessible web-based version, which can be used for capacity development and knowledge transfers in order to facilitate transparency of decision-making (possibly in form of a serious game).

F Summary

Problem description and motivation of this thesis

Still, every third human being on this planet (2.5 billion people) does not have access to improved sanitation. An estimated 15% of the world population practices open defecation in public areas. Particularly in densely populated and economically weak urban areas this leads to precarious living conditions. Some studies say, that more than 700,000 children die every year from forms of diarrhoea, which are directly related to a lack of sanitation and supply of clean water.

Wherever infrastructure systems are missing or not adapted to the local context, untreated wastewater and solid waste are being disposed of directly. This results in a large-scale contamination of the environmental compartments of soil and water in and around urban settlements.

The conventional approach in urban water management produces wastewater by mixing of domestic part-material flows with drinking water and (ideally) transporting this form of liquid waste via a sewer system to a wastewater treatment plant. Resources, which are contained in the wastewater stream (mainly the macronutrients N, P, K, water and energy), are not used, but are disposed in a costly manner. In particular, the nutrient P, which is essential for plant growth, is a limited resource and critical for the food security of the world population. The estimated availability of the world's accessible phosphorus reserves will last only for the next 60-150 years.

The modern conventional wastewater technology has originally been designed for solving problems of the industrialized countries of middle Europe in the late 19th century. This technological approach, whose main purpose is to secure urban hygiene, is (if at all) only partially transferable to many areas of developing countries in Europe, America, Asia and Africa. The main reasons for this are ***ecological*** (water scarcity, waste of resources), ***economical*** (high costs, missing flexibility, extensibility) and ***structural*** (non-adapted, expensive, difficult-to-operate technology, maintenance, management) ***characteristics***, which cannot be adapted to the prevalent local frame conditions.

Goals of the work presented here are on the one hand the elaboration of general principles of integrated sanitation systems and evaluate their suitability by using the example of a pilot project in the city of Darkhan in Mongolia. Further on such an integrated sanitation system should be visualised in a software-based mathematical model and different scenarios should be evaluated.

The results of the simulation should be usable as decision support for the further design and planning of an integrated system. Equally the model-based consideration has been done using the case study of Darkhan, Mongolia.

State of Science

The imperfection of the conventional wastewater technology was commonly known by the experts of the late 19th century in Europe. **Integrated approaches** of different technologies for collection, transport, and treatment of part-material-flows (e.g. urine, faeces, faecal sludge, domestic solid waste) have already been practiced at that time. Experts also demanded such adaptable approaches for the future development of urban hygiene systems.

In the solid waste management sector, the principle of circular economy has been established as a worldwide accepted state-of-science and technology. Experts from the urban water management sector increasingly demand for an inclusion of the principles of circular economy and start to apply them. However, a fundamental change of the current paradigm of conventional wastewater systems is not in sight. The opening of the conventional approach towards more sustainable forms of urban water management is overdue.

Now, in the early 21st century, the need for integrated approaches is obvious, in particular for rapidly changing urban environments with underdeveloped infrastructure. The **adherence to** the **conventional approach is** now **prohibiting progress** and is in many cases responsible for malfunctioning or non-existent infrastructure systems.

In this thesis it is therefore hypothesized, that an **integrated sanitation** system (iSaS), which is **based on material** flows, **communication**-flows, and **monetary flows**, would be able to identify the short-comings of current sanitation systems and reveal ecological and economical potentials. Integrated sanitation would offer an approach, which would contribute to the solution of the above-named problems.

In Germany, new alternative sanitation systems (NASS) have been developed as a potentially suitable approach for the renewal of the urban water management sector. Worldwide, a number of different approaches for different climate zones, urban and rural, and differing economic backgrounds have been developed, for instance *community-led total sanitation (CLTS)“, „community-led urban environmental sanitation (CLUES)“, „ecological sanitation (ecosan)“* or *„sustainable sanitation (SuSan)“.* Most of the approaches are resource-based and include a source-separated consideration of material-flows. So far, these approaches exist side-by-side and have not been harmonized. So far, an integrated approach is not described in detail.

Methods used

An extensive literature study has been carried out to describe the state-of-science. Further on an integrated sanitation system has been developed and implemented in a pilot scale in the city of

Darkhan, Mongolia. The iSaS has been operated and monitored over a period of 2 years by taking the standpoint of applied engineering sciences. The systematic approach in the Darkhan case followed mainly the here elaborated principles of integrated sanitation.

By applying an interdisciplinary, participatory planning approach, the planning and implementation of the iSaS in Darkhan has been carried out, as described in CLUES. The method has been adapted to the local circumstances in Mongolia. The pilot project has equally been evaluated according to methods from social sciences and from economic standpoints. This included, among other methods, stakeholder analysis, analysis of local market prices for technical components and construction, as well as cost comparative calculations. Further on the principles of iSaS were used to evaluate the pilot project.

The Darkhan case has also been used as basis for the implementation of the mathematical model of iSaS. It is built upon a combined usage of the software MATLAB®, Simulink®, and MS Excel®. The spreadsheet software is only used to organise the basic input parameters, to define assumptions as well as to specify the sources of information and valuate the quality of the used data. The graphical user interface for the model-based development in Simulink® helps to structure and control the complex iSaS model. Different scenarios and possibilities for adjustment have been built into the model. It also enables the assessment of data at any point within the model and can be used for decision-making.

Main findings

In the present dissertation, a basis for an integrated planning approach for sanitation has been developed and the notion *"integrated sanitation system (iSaS)"* has been defined for the first time. Among others the definition is derived from historical problems. The necessity to develop flexible and combined technological and organisational approaches has been pointed out at a very early stage during the extension of sanitation systems in European cities in the late 19th century. The definition of iSaS in particular considers the special circumstances of countries, whose infrastructure is underdeveloped.

The participatory approach for the planning and implementation of iSaS in Darkhan has proved to be supportive in the process. It has been shown that the iSaS approach enhances the transparency of the planning process and promotes the understanding and acceptance of the sanitation system. The high level of transparency can create a supportive environment for the implementation of sanitation in countries with a high prevalence of corruption.

With the development of the urine diversion dry toilet **iPiT®** and its complementary technologies (e.g. emptying service, biogas plant) a **practicable technical concept** has been demonstrated. It was possible to show its functionality and usefulness in an urban environment, which would otherwise have a complete lack of sanitation infrastructure. For Mongolia, the iSaS based on iPiT® and biogas plant is the most suitable system in comparison to alternative technical options.

Further on is shown that marketable technologies for a broad implementation of sanitation systems based on UDDTs are not yet available. For the spread of this approach it is essential to design a marketable solution. A solution can only be achieved through a total consideration of a continuous technology chain for collection, transport, treatment, and reuse. This should preferably be done with a high grade of detail. In particular, for the toilet as the interface between user and system, some fundamental minimum requirements have been defined in this dissertation.

The mathematical model of the iSaS Darkhan enables a clear presentation of the interconnected material-flows, energy-flows, and monetary-flows. Different scenarios are visualised and the influence of the variation of different parameters (e.g. prices for fertilizer, demography, costs) on the system can be examined. The results can be used to support decision-making and enhance the understanding of interdependent processes within the system. The development stage of the model is not yet suitable for the end-user. Extended functionalities and adaption to different locations can be built into the model according to the particular needs of a user. Consequently, the model will not be finished and remains work in progress.

The model has been applied and tested by comparing the conventional approach of a wastewater treatment system with the proposed iSaS with iPiT® of the Darkhan case. Different scenarios have been developed and analysed. It was shown that the conventional system is by far out of reach of being affordable and re-financeable. Additionally, it has a lot of ecological disadvantages.

Even the iSaS is not automatically affordable, but has a very high potential to deliver a cost-effective and ecological safe solution. The combination of the four following measures will lead to a complete cost recovery rate of the integrated sanitation system in Darkhan:

1. Enhance the “willingness-to-pay” and collect justifiable fees from the users through different measures (participation in investment, cross-financing, rental models, community-owned models).
2. Push down prices for investment costs of the iPiT® (mass production) and the new *material-flow treatment facility* (optimized process design).
3. Optimise O&M costs of the treatment processes at the new material-flow treatment facility.
4. Unleash the potential of NPK resource recovery by creating a market for fertiliser products from iSaS.

G Bibliography

List of literature:

ADB. (2016). Bringing Clean Water to Mongolian Towns I Asian Development Bank. Retrieved May 24, 2016, from http://www.adb.org/results/bringing-clean-water-mongolian-towns

Alfen, H. W., Kalidindi, S. N., Ogunlana, S., Wang, S., Abednego, M. P., Frank-Jungbecker, A., … Zhao, G. (2009). *Public-Private Partnership in Infrastructure Development: Case Studies from Asia and Europe*. (H. W. Alfen, Ed.) (Vol. 7). Weimar, Germany: Bauhaus-Universität Weimar Verlag.

ATV. (1999). *Geschichte der Abwasserentsorgung*. Hennef, Germany: Gesellschaft zur Förderung der Abwassertechnik e. V. (GFA).

Badran, M., Jamrah, A., & Gaese, H. (2010). Assessment of a cost-covering sanitation tariff for Alexandria/Egypt, *175*, 17. Retrieved from http://www.susana.org/lang-en/library?view=ccbktypeitem&type=2&id=693

Basandorj, D., & Altanzagas, B. (2007). Current situation and key problems on water supply and sanitation in Mongolia. In *2007 International Forum on Strategic Technology* (pp. 166–168). IEEE. http://doi.org/10.1109/IFOST.2007.4798550

Batimaa, P., Myagmarjav, B., Batnasan, N., Jadambaa, N., & Khishigsuren, P. (2011). *Urban Water Vulnerability to Climate Change in Mongolia*. Ulaanbaatar, Mongolia: Water Authority: Government of Mongolia.

Battsengel, V., & Janzen, J. (2010). *Structure and Delineation of the Economic Region of Darkhan City*. Ulaanbaatar, Mongolia: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Benedetti, L., Dirckx, G., Bixio, D., Thoeye, C., & Vanrolleghem, P. a. (2008). Environmental and economic performance assessment of the integrated urban wastewater system. *Journal of Environmental Management*, *88*(4), 1262–1272. http://doi.org/10.1016/j.jenvman.2007.06.020

Berlin-Institut für Bevölkerung und Entwicklung. (2014). Online-Handbuch Demografie. Retrieved August 14, 2014, from http://www.berlin-institut.org/index.php?id=11

Bjarsch, B. (1997). 125 Jahre Berliner Rieselfeld-Geschichte. *Wasser und Boden*, *49*(3), 45–48. Retrieved from http://cat.inist.fr/?aModele=afficheN&cpsidt=2617882

BMBF. (2009). *Integrated Water Resources Management for Central Asia: Model Region Mongolia (MoMo) - Case Study in the Kharaa River Basin (Final Report)*. Mongolia;

Germany: Ministerium für Bildung und Forschung (BMBF).

BMZ. (2008). *Entwicklungszusammenarbeit im Bereich Siedlungshygiene und Abwassermanagement* (BMZ Spezial 158). (C. Merdes, K. Dölle, V. Pfeiffer, S. Lorek, & J. Wagner, Eds.). Bonn; Berlin, Germany.

Böhm, M., Lauckner, M., & Seyfarth, R. (2013). *Development of an Integrated Solid Waste Management System: Recommendations for the Ger-Settlement Bag7 in Darkhan, Mongolia*. Bauhaus-Universität Weimar, Weimar, Germany.

Böhme, C. (2014). *Co-Composting of Solid Organic Waste and Faecal Sludge from Urban Waste Water for the City of Battambang, Cambodia* (Bachelor Thesis). Bauhaus-Universität Weimar, Weimar, Germany.

Borchardt, D., Hufert, F., Karthe, D., Scharaw, B., Sigel, K., & Stäudel, J. (2012). Towards an integrated concept for monitoring and improvements in water supply, sanitation and hygiene (WASH) in urban Mongolia. *WHOCC Newsletter Universität Bonn*, *20*(July 2012), 1–8. Retrieved from www.ipit.eu

Borchardt, D., & Ibisch, R. (2013). *Integrated Water Resources Management in a Changing World*. (D. Borchardt & R. Ibisch, Eds.). London, UK: IWA Publishing. Retrieved from http://iwapublishing.com/template.cfm?name=isbn9781780405261__&type=category

BRD. Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz - WHG) (2009). Berlin: Bundesrepublik Deutschland.

Brunner, P. H., & Rechberger, H. (2004). *Practical handbook of material flow analysis*. Taylor & Francis Group.

Bruski, C. (2015). *Gemeinsame Faulung von Klärschlamm und Fäzes unter extremen klimatischen Bedingungen - Beispiel Mongolei*. *Schriftenreihe des Bauhaus-Instituts für zukunftsweisende Infrastruktursysteme (b.is)* (Vol. 16). Dissertation, Weimar, Germany: Rhombos-Verlag Berlin.

BUW, INAWA, & Tuttahs & Meyer GmbH. (2010). *Auswirkungen des demografischen Wandels auf die technische Infrastruktur von Abfallentsorgung , Wasserversorgung und Abwasserbeseitigung in ländlichen Regionen in den neuen Bundesländern (Endbericht)*.

Chadwick, E. (1842). *Report on the Sanitary Condition of the Labouring Population and on the Means of its Improvement*. London, U.K. Retrieved from http://www.victorianweb.org/history/chadwick2.html

Chadwick, E. (1843). *Report on the Sanitary Condition of the Labouring Population of Great Britain: A Supplementary Report on the Results of a Spiecal Inquiry Into the Practice of Interment in Towns*. book, London, U.K.: W. Clowes and Sons. Retrieved from https://books.google.de/books?id=8aE9AAAAcAAJ

Climate-Data.org. (2016). Climate: Darkhan - Climate graph, Temperature graph, Climate table - Climate-Data.org. Retrieved May 8, 2016, from http://en.climate-data.org/location/29830/

Cordell, D. (2010). *The Story of Phosphorus - Sustainability implications of global phosphorus scarcity for food security* (Dissertation). Linköping University, Sweden; University of Technology, Sydney, Linköping, Sweden.

Cordell, D., Drangert, J.-O., & White, S. (2009). The Story of Phosphorus: Global Food Security and Food for Thought. *Global Environmental Change*, *19*(2), 292–305. http://doi.org/10.1016/j.gloenvcha.2008.10.009

D-Waste. (2012). *Waste Management For Everyone*. Retrieved from http://www.d-waste.com/images/stories/virtuemart/product/D-Waste Concept.pdf

Dockhorn, T. (2007). *Stoffstrommanagement und Ressourcenökonomie in der kommunalen Abwasserwirtschaft* (Habilitation). Ges. zur Förderung des Institutes für Siedlungswasserwirtschaft an der Techn. Univ. Braunschweig, Braunschweig.

Dolgorsuren, G., Bron, J., & van der Linden, W. (2012). *Integrated Water Management - National Assessment Report Volume II* (Vol. II). Mongolia.

Duden. (2016). Duden I In-te-g-ra-ti-on I Rechtschreibung, Bedeutung, Definition, Synonyme, Herkunft. Retrieved January 31, 2016, from http://www.duden.de/rechtschreibung/Integration

Dunbar, W. P. (1907). *Leitfaden für die Abwasserreinigungsfrage* (3. Edition). München, Germany: Verlag von R. Oldenbourg.

DWA. (2009). *Neuartige Sanitärsysteme*. (Weiterbildendes Studium Wasser und Umwelt, Ed.) (1. Auflage). Weimar, Germany: Bauhaus-Universitätsverlag Weimar.

DWA. (2010). Do we need New Alternative Sanitation Systems in Germany ? (DWA, Ed.). Hennef, Germany: Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA)Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA).

DWA. (2012). *Leitlinien zur Durchführung Dynamischer Kostenvergleichsrechnungen (KVR-Leitlinien)*. (Herausgeber der 1. bis 7. Aufl. Bund/Länder-Arbeitsgemeinschaft Wasser (LAWA), Ed.) (8. überarb). Berlin, Germany: DWA Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.

DWA. (2014). *Arbeitsblatt DWA-A 272: Grundsätze für die Planung und Implementierung Neuartiger Sanitärsysteme (NASS)* (Arbeitsblatt). Hennef, Germany: Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA).

DWA. (2015). *Neuartige Sanitärsysteme*. (Weiterbildendes Studium Wasser und Umwelt, Ed.) (2. Auflage). Weimar, Germany: Bauhaus-Universitätsverlag Weimar.

EAWAG. (2005). *Household-Centred Environmental Sanitation: Implementing the Bellagio Principles in Urban Environmental Sanitation*. Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (EAWAG).

Eigenbrodt, K. (1868). *Die Städtereinigung zur Verhütung der steigenden Verunreinigung des Erdbodens unserer Wohnorte als wichtigste Aufgabe der Sanitätspolizei*. Darmstadt & Leipzig, Germany: Eduard Zernin.

Eitinger, T., Fuchs, G., Heider, J., Kemper, B., Kothe, E., Schink, B., … Unden, G. (2007). *Allgemeine Mikrobiologie*. (G. Fuchs, Ed.) (8., vollst). Stuttgart, New York: Georg Thieme Verlag. http://doi.org/10.1016/0014-5793(81)80456-5

Fach, S. (2013). *Bewertung der Abwasserbehandlung in Entwicklungs- und Schwellenländern. Schriftenreihe SWW Karlsruhe*. Karlsruhe, Germany: Institutsverlag Siedlungswasserwirtschaft.

Feldmann, U. (2013). *Ermittlung des weltweiten Verbreitungspotentials eines stoffstrom-basierten, integrierten Sanitärsystems basierend auf iPiT®, angepasster Behandlung und gewinnbringender Verwertung organischer Reststoffe*. Bauhaus-Universität Weimar, Weimar, Germany.

Gawel, E., Sigel, K., & Bretschneider, W. (2011). Affordability of Water Supply in Mongolia: Empirical Lessons for Measuring Affordability. *UFZ Discussion Papers*, (November), 29.

GIZ, Rieck, C., von Münch, E., & Hoffmann, H. (2012). *Technology Review of Urine-diverting dry toilets (UDDTs)*. (C. Rieck, Ed.). Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Grambow, C., Lamkowsky, G., & seeconsult GmbH. (2013). *Monitoring der 12 Versuchsaushalte in Rahmen der Einführung der iPiT in der Ger Siedlung Darkhan, Mongolei*.

Grambow, M. (2008). *Wassermanagement: Integriertes Wasser-Ressourcenmanagement von der Theorie zur Umsetzung*. Wiesbaden, Deutschland: Friedrich Vieweg & Sohn Verlag. Retrieved from http://books.google.com/books?hl=en&lr=&id=0-QyJyzl3PQC&oi=fnd&pg=PA1&dq=Wassermanagement+Integriertes+Wasser-Ressourcenmanagement+von+der+Theorie+zur+Umsetzung&ots=eVIC4t_k-6&sig=BU15NzfFuCVk4HhJVquKoLRINGc

Gruber, v. O., & Brunner, L. (1871). *Canalisation oder Abfuhr? - Eine staatswirtschaftliche Frage*. Berlin, Germany: Verlag von Wiegand und Hempel; Landwirtschaftliche Verlagsbuchhandlung.

Grunert, J., & Stolz, C. (2009). *Große Geländeübung: Mongolei (Exkursionsführer)*. Mainz, Germany.

GTZ ecosan team. (2010a). *National strategies and programmes within the water and sanitation sector*. Eschborn, Germany.

GTZ ecosan team. (2010b). *Worldwide list of documented ecosan projects by various organisations*. Eschborn, Germany.

Gutjahr, F. (2013). *Entwicklung von angepassten Gebührensystemen für integrierte Sanitärsysteme in Jurtensiedlungen in der Mongolei*. Bauhaus-Universität Weimar, Weimar, Germany.

GWP, & INBO. (2009). *A Handbook for Integrated Water Resources Management in Basins*. Istanbul, Turkey: Global Water Partnership (GWP); International Network of Basin Organizations (INBO). Retrieved from www.gwpforum.org

GWP, & INBO. (2012). *The Handbook for Integrated Water Resources Management in Transboundary Basins of Rivers, Lakes and Aquifers*. (G. Sine, Trans.). International Network of Basin Organizations (INBO); Global Water Partnership (GWP). Retrieved from www.inbo-news.org

Halbach, U. (2003). *Kommunale Abwasserbeseitigung: Normative Kosten und Risikoabbau*. (Uwe Halbach, Ed.). Werdau, Germany: Institut für Wasserwirtschaft Halbach.

Harbach, M. (2011). *Franchising im Wassersektor: Ableitung und Beschreibung eines alternativen Geschäftsmodells für Dienstleistungen der Wasserver- und Abwasserentsorgung* (Schriftenreihe Umwelttechnik und Umweltmanagement). (K.-U. Rudolph, Ed.). Cuvillier Verlag, Witten/Herdecke, Germany.

Harbach, M., Rudolph, K.-U., & Block, T. (2011). A business driven approach for sustainable IWRM and local economic development. In *International Conference on Integrated Water Resources Management* (p. Section B-3). Dresden, Germany: BMBF.

Hein, A., Lévai, P., & Wencki, K. (2015). Multikriterielle Bewertungsverfahren: Kurzbeschreibung und Defizitanalyse (Teil 1-3). *GWF Wasser Abwasser Fachberichte Wasserinfrastrukturen*, *156*(1, 2, 3), 58–61, 202-212-336.

Herrle, P., Jachnow, A., Samol, F., Vest, H., Shorbagi, M. el, & Bockelmann, D. (2005). *Improvement of Sanitation and Solid Waste Management in Urban Poor Settlements*. (Frank Samol B.U.S. - Büro für Umweltplanung und Stadtentwicklung Dresden, Ed., B. Kern, L. Quitzow, & F. Samol, Trans.). Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Hiessl, H., Walz, R., & Toussaint, D. (2001). Design and Sustainability Assessment of Scenarios of Urban Water Infrastructure Systems. In *5th International Conference on Technology,* *Policy and Innovation* (p. 11). Delft, The Netherlands.

Hillenbrand, T., Menger-Krug, E., Klug, S., Niederste-Hollenberg, J., Holländer, R., Lautenschläger, S., & Geyler, S. (2010). *Demografischer Wandel als Herausforderung für die Sicherung und Entwicklung einer kosten- und ressourceneffizienten Abwasserinfrastruktur*. Dessau-Roßlau, Germany.

Hofmann, J., Hürdler, J., Ibisch, R., Schaeffer, M., & Borchardt, D. (2011). Analysis of Recent Nutrient Emission Pathways, Resulting Surface Water Quality and Ecological Impacts under Extreme Continental Climate: The Kharaa River Basin (Mongolia). *International Review of Hydrobiology*, *96*(5), 484–519. http://doi.org/10.1002/iroh.201111294

Hofmann, J., Tuul, D., & Enkhtuya, B. (2016). Chapter 19: Agriculture in Mongolia Under Pressure of Agronomic Nutrient Imbalances and Food Security Demands: A Case Study of Stakeholder Participation for Future Nutrient and Water Resource Management. In D. Borchardt, J. J. Bogardi, & R. B. Ibisch (Eds.), *Integrated Water Resources Management: Concept, Research and Implementation* (pp. 471–514). Heidelberg; New York, Germany; USA: Springer International Publishing Switzerland.

Horlemann, L., & Dombrowsky, I. (2010). Institutionalizing IWRM in Developing and Transition Countries – The Case of Mongolia. *UFZ Discussion Papers*, (July 2010), 25. Report.

Hösel, G. (1990). *Unser Abfall aller Zeiten - Eine Kulturgeschichte der Städtereinigung*. München, Germany: Kommunalschriften-Verlag J. Jehle München GmbH.

Houdret, A., Dombrowsky, I., & Horlemann, L. (2013). The institutionalization of River Basin Management as politics of scale – Insights from Mongolia. *Journal of Hydrology*, 13. http://doi.org/10.1016/j.jhydrol.2013.11.037

Howard, G., Bartram, J., & WHO. (2003). *Domestic Water Quantity, Service Level and Health. World Health Organization*. Geneva, Switzerland: WHO. http://doi.org/10.1128/JB.187.23.8156

Huuhtanen, S., & Laukkanen, A. (2006). *A Guide to Sanitation and Hygiene for those Working in Developing Countries*. (M. Korkeakoski, Ed.) (Updated Ve). Tampere, Finland.

IFDC, & Van Kauwenbergh, S. (2010). *World Phosphate Rock Reserves and Resources. IFDC Publications*. USA. http://doi.org/ISBN 978-9-88999-167-3

iReBa Team. (2014). *iReBa: Integrated Resources Management Battambang* (Student Project). Bauhaus-Universität Weimar, Weimar, Germany.

Jacobsen, M., Webster, M., & Vairavamoorthy, K. (2013). *The Future of Water in African Cities - Why Waste Water?* (M. Jacobsen, M. Webster, & K. Vairavamoorthy, Eds.). Washington D.C., USA: World Bank. http://doi.org/10.1596/978-0-8213-9721-3

Jönsson, H., Stintzing, A. R., Vinnerås, B., & Salomon, E. (2004). *Guidelines on the Use of Urine and Faeces in Crop Production*. Stockholm, Schweden: he EcoSanRes Programme; Stockholm Environment Institute (SEI).

Jurga, I. (2009). *Workshop report Erdos Eco-Town Project : Lessons learned and ways forward*. Beijing, China, China: EcoSanRes Programme, Stockholm Environment Institute; USTB. Retrieved from http://www.ecosanres.org/pdf_files/ErdosWorkshop-FinalReport.pdf

Kar, K. (2010). *Workshops for Community-Led Total Sanitation*. Geneva, Switzerland: Water Supply & Sanitation Collaborative Council (WSSCC).

Kar, K., & Chambers, R. (2008). *Handbook on Community-Led Total Sanitation. Children*. London, United Kingdom: Plan UK. Retrieved from http://www.communityledtotalsanitation.org/sites/communityledtotalsanitation.org/files/cltshandbook.pdf

Karthe, D., Heldt, S., Rost, G., Londong, J., Ilian, J., Heppeler, J., … Borchardt, D. (2016). Chapter 25 Modular Concept for Municipal Water Management in the Kharaa River Basin, Mongolia. In D. Borchardt, J. J. Bogardi, & R. B. Ibisch (Eds.), *Integrated water resources management: Concept, Research and Implementation* (pp. 649–681). Springer International Publishing Switzerland. http://doi.org/10.1007/978-3-319-25069-4

Keating, J. M. (1880). The Value of Sanitation from an Economic Stand-Point. *Public Health Papers and Reports*, *6*, 266–278.

Keipp, W., Schuen, R., & Hoffmann, H. (2013). *Integrated Urban Sanitation at Scale - Discussion Paper*. (KfW Development Bank & Competence Center Water and Solid Waste Management, Eds.). Frankfurt am Main, Germany: KfW Bankengruppe. Retrieved from www.kfw.de

Khuldorj, B., Bum-Ayush, M., Dagva, S., Myagmar, D., & Shombodon, D. (2012). *Mongolia's Sustainable Development Agenda: Progresses, Bottlenecks and Vision for the Future*. Ulaanbaatar, Mongolia: United Nations Development Programme (UNDP).

King, F. H. (1911). *4000 Jahre Landbau in China, Korea und Japan* (Edition Si). München, Germany: Volkswirtschaftlicher Verlag.

Koppe, P., & Stozek, A. (1999). *Kommunales Abwasser : seine Inhaltsstoffe nach Herkunft, Zusammensetzung und Reaktionen im Reinigungsprozeß einschließlich Klärschlämme*. Essen, Germany: Vulkan-Verlag Essen.

KrWG. Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz - KrWG) (2013). Bundesministerium der Justiz.

Lamkowsky, G., Saladin, M., & seeconsult GmbH. (2014). Partizipative Methoden: Erfahrungen zur verbesserten Siedlungswasserwirtschaft in der Mongolei. Osnabrück, Germany: seeconsult GmbH – partizipatives Planen für die Umwelt. Retrieved from http://www.seeconsult.org/en/

Lange, J., & Otterpohl, R. (1997). *Abwasser: Handbuch zu einer zukunftsfähigen Wasserwirtschaft* (1. Auflage). Donaueschingen-Pfohren, Germany: Donaueschingen-Pfohren : Mall-Beton-Verlag.

Larsen, T. A., Udert, K. M., & Lienert, J. (2013). *Source Separation and Decentralization for Wastewater Management*. (T. A. Larsen, K. M. Udert, & J. Lienert, Eds.), *IWA Publishing*. London, UK: IWA Publishing 2013.

Lauckner, M. (2013). *Implementierung einer thermischen Abfallbehandlungsanlage*. Bauhaus-Universität Weimar, Weimar, Germany.

Leeuwen, C. J., Frijns, J., Wezel, A., & Ven, F. H. M. (2012). City Blueprints: 24 Indicators to Assess the Sustainability of the Urban Water Cycle. *Water Resources Management*, *26*(8), 2177–2197. http://doi.org/10.1007/s11269-012-0009-1

Lindemann, H. (1901). *Die deutsche Städteverwaltung: ihre Aufgaben auf den Gebieten der Volkshygiene, des Städtebaus und des Wohnungswesens*. book, Stuttgart, Germany: J.H.W. Dietz nachf. Retrieved from https://books.google.de/books?id=WAEOAAAAYAAJ

Londong, J. (2009). Neue Konzepte zur Abwasserentsorgung. In *Schriftenreihe Gewässerschutz – Wasser – Abwasser* (Vol. 218, p. 3/1-3/8). Aachen, Germany.

Londong, J., Stäudel, J., Rost, G., Bruski, C., & Hartmann, M. (2014). *Integriertes Wasserressourcen-Management in Zentralasien: Modellregion Mongolei, Phase II (MoMo2) - Ganzheitliche, stoffstromorientierte Betrachtung der Siedlungswasserwirtschaft als Baustein eines IWRM*. Weimar, Germany: Bundesministerium für Bildung und Forschung /

Federal Ministry of Education and Research (BMBF). http://doi.org/10.2314/GBV:843607491

Lüthi, C., & Larsen, T. A. (2014). Sanitation Innovation for Urban Slums: the Blue Diversion Toilet. In *2014 Tech4Dev International Conference* (p. 7). Lausanne, Switzerland: EPFL. Retrieved from http://cooperation.epfl.ch/2014Tech4Dev

Lüthi, C., Morel, A., Tilley, E., & Ulrich, L. (2011). *Community-Led Urban Environmental Sanitation Planning (CLUES).* (H. B. Johnston, Ed.) (1st Editio). Dübendorf, Switzerland: Swiss Federal Institute for Environmental Science and Technology (EAWAG); Sanitaion in Developing Countries (SanDeC); Water Supply and Sanitation Collaborative Council (WSSCC); UN-HABITAT.

Lüthi, C., Panesar, A., Schütze, T., Norström, A., McConville, J. R., Parkinson, J., … Ingle, R. (2011). *Sustainable Sanitation in Cities*. (C. Lüthi & T. Schütze, Eds.) (First Edit). Rijswijk, Netherlands: Papiroz Publishing House.

Makropoulos, C. K., Natsis, K., Liu, S., Mittas, K., & Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management. *Environmental Modelling and Software*, *23*(12), 1448–1460. http://doi.org/10.1016/j.envsoft.2008.04.010

Maquet, C. (1898). Das Abfuhrsystem für die Städtereinigung. *Sammlung von Abhandlungen, Gutachten und Vorträgen über Städtereinigung und Verwerthung städtischer Abfallstoffe für die Landwirthschaft*, *1*, 36.

Masurel, E., & Nijkamp, P. (2009). The low participation of urban migrant entrepreneurs: Reasons and perceptions of weack institutional embeddedness. *Research Memorandum 2009-40*, *2009*(40), 23.

Medina, M. (2008). The informal recycling sector in developing countries: Organizing waste pickers to enhance their impact. *Gridlines*, (44), 1–4.

Meinzinger, F. (2010). *Resource Efficiency of Urban Sanitation Systems: a Comparative Assessment Using Material and Energy Flow Analysis* (Dissertation). Gesellschaft zur Förderung und Entwicklung der Umwelttechnologien an der Technischen Universität Hamburg-Harburg e.V. (GFEU), Hamburg; Harburg, Germany.

Menzel, L., Hofmann, J., & Ibisch, R. (2011). Untersuchung von Wasser- und Stoffflüssen als Grundlage für ein Integriertes Wasserressourcen- Management im Kharaa-Einzugsgebiet, Mongolei. *Hydrologie und Wasserbewirtschaftung*, *55*(2), 88–103.

Metcalf & Eddy Inc. (2003). *Wastewater Engineering: Treatment and Reuse*. (G. Tchobanoglous, F. L. Burton, & H. D. Stensel, Eds.) (4. Interna). New York, USA: McGraw-Hill Education.

Metcalf & Eddy Inc. (2014). *Wastewater Engineering: Treatment and Resource Recovery*. (G. Tchobanoglous, H. D. Stensel, R. Tsuchihashi, & F. Burton, Eds.) (5. Edition). New York, USA: McGraw-Hill Education.

Mitchell, V. G. (2006). Applying integrated urban water management concepts: a review of Australian experience. *Environmental Management*, *37*(5), 589–605. http://doi.org/10.1007/s00267-004-0252-1

Mittermaier, K. (1870). *Die Reinigung und Entwässerung der Stadt Heidelberg*. Heidelberg, Germany: Verlagsbuchhandlung von Fr. Bassermann.

Mittermaier, K. (1897). Das Heidelberger Tonnensystem, seine Begründung und Bedeutung. *Sammlung von Abhandlungen, Gutachten und Vorträgen über Städtereinigung und Verwerthung städtischer Abfallstoffe für die Landwirthschaft*, *1*, 29. Retrieved from http://books.google.de/books?id=53RDMwAACAAJ

Möllring, B. (2003). *Toiletten und Urinale für Frauen und Männer - die Gestaltung von*

Sanitärobjekten und ihre Verwendung in privaten und öffentlichen Bereichen (Dissertation). Germany.

Montgomery, D. R. (2010). *Dreck: warum unsere Zivilisation den Boden unter den Füßen verliert*. book, München, Deutschland: Oekom Verlag GmbH.

National Statistical Office of Mongolia. (2013). Mongolian Statistical Yearbook 2012, *2012*, 460.

Nayono, S. (2014). *Development of a Sustainability-based Sanitation Planning Tool (SusTA) for Developing Countries* (Disseration). Bauhaus-Universität Weimar, Weimar, Germany.

Niwagaba, C. B. (2009). *Treatment Technologies for Human Faeces and Urine* (Dissertation). Swedish University of Agricultural Sciences, Uppsala, Sweden.

Numbeo. (2016). Pollution Index Rate. Retrieved May 8, 2016, from http://www.numbeo.com/pollution/rankings_current.jsp

Ottow, J. C. G., Bidlingmaier, W., Diekert, G., Fischer, K., Flemming, H.-C., Heinemann, A., … Scholz-Muramatsu, H. (1997). *Umweltbiotechnologie*. (J. C. G. Ottow & Werner Bidlingmaier, Eds.) (1. Auflage). Stuttgart, Germany: Gustav Fischer.

Oxford Advanced Learner's Dictionary. (2016). integration noun - Definition, pictures, pronunciation and usage notes | Oxford Advanced Learner's Dictionary at OxfordLearnersDictionaries.com. Retrieved January 31, 2016, from http://www.oxfordlearnersdictionaries.com/definition/english/integration?q=integration

Parliament of Mongolia. "Water" National Programme (2010). Ulaanbaatar, Mongolia.

Peters, D. M. (2012). *Assessing the Sustainability of Ecological Sanitation*. University of Basel, Basel, Switzerland.

Pfammatter, R., & Schertenleib, R. (1996). *Non-Governmental Refuse Collection in Low-income Urban Areas: Lessons Learned from Selected Schemes in Asia, Africa and Latin America. Sandec News* (Vol. 96). Duebendorf, Switzerland: EAWAG: Swiss Federal Institute of Aquatic Science and Technology.

Pieper, C. (1869). *Schwemmcanäle oder Abfuhr? - Eine Frage und Abstimmung*. Dresden, Germany: Verlag der Bach'schen Buchhandlung (Otto Kubel).

Prasad, N. (2006). Current issues in Private sector participation (PSP) in water services. *Development Policy Review*, *24*(6), 669–692.

Reckerzügel, T., Gutterer, B., Sasse, L., & Panzerbieter, T. (2009). Decentralised Wastewater Treatment Systems (DEWATS) and Sanitation in Developing Countries, *49*, 28.

Reichelt, P. (2006). *Vergessene Landschaft Rieselfelder: Eine Zeitreise durch 200 Jahre Geschichte*. Teltow, Germany: Eigenverlag.

Remy, C. (2010). *Life cycle assessment of conventional and source separation systems for urban wastewater management* (THES). *Cycle*. Technische Universität Berlin, Berlin. Retrieved from http://nbn-resolving.de/urn:nbn:de:kobv:83-opus-25430

Renner, G. (2014). *Untersuchung des Einflusses unterschiedlicher Ernährungsgewohnheiten auf die Nährstoffzusammensetzung und das mögliche Biogaspotenzial von Fäzes* (Master Thesis). Bauhaus-Universität weimar, Weimar, Germany.

Riechmann, M. (2013). *Identifikation und Beschreibung der Kernelemente eines funktionalen Designs eines leitungsungebundenen, stoffstrombasierten Sanitärsystems anhand der iPiT®*. Bauhaus-Universität Weimar, Weimar.

Römer, C. (2006). *Aktuelle Migrationsprozesse und ihre Auswirkungen auf die Stadtentwicklung von Darkhan/Mongolei. Eine sozialgeographische Untersuchung zu Hintergründen, Ablauf und Formen des jungen Wandels unter besonderer Berücksichtigung der Jurtenviertel*

(Diplomarbeit). Geographisches Institut der Universität Mainz.

Rost, G., & Londong, J. (2013). Development of a Toolbox-Model for Integrated Urban Water Management - Case Study Area Darkhan, Kharaa Catchment, Mongolia. In *Istanbul International Solid Waste, Water And Wastewater Congress 2013* (pp. 1463–1471).

Rost, G., Londong, J., Dietze, S., & Osor, G. (2014). Integrated urban water management: development of an adapted management approach. *Environmental Earth Sciences*, *Thematic I*, 10. http://doi.org/10.1007/s12665-014-3701-z

Rutland, D., & Polo, J. (2005). *Fertilizer Dealer Handbook - Products, Storage, and Handling*. *IFDC Publications*. Alabama, USA. Retrieved from www.ifdc.org

Sasse, L. (1998). *DEWATS Decentralised Wastewater Treatment in Developing Countries*. Bremen: Bremer Arbeitsgemeinschaft für Überseeforschung und Entwicklung.

Schüßler, A. B. (2011). *Grey Water Treatment Units in Ger Settlements in Ulaanbaatar, Mongolia (Work Report)*. Action contre la Faim (ACF) Mongolia.

Schuster, C. (2011). *Description of Waste Management for the City of Darkhan*. Bauhaus-Universität Weimar, Weimar, Germany.

Schuster, C. (2012). *Technische Entwicklung und ökonomischer Vergleich angepasster, leitungsungebundener Sanitärsysteme mit integrierter Abfallentsorgung für Jurten-Siedlungen in der Stadt Darkhan, Mongolei*. Bauhaus-Universität Weimar, Weimar, Germany.

Schweitzer, C. (2012). *Modelling land-use and land-cover change and related environmental impacts in Northern Mongolia*. Martin-Luther-Universität Halle-Wittenberg, Halle, Germany.

seecon GmbH. (2016). Sustainable Sanitation and Water Management Toolbox. Retrieved April 14, 2016, from http://www.sswm.info/

seeconsult GmbH. (2011). *Protokoll Launching-Workshops in Darkhan, Mongolei 30.09.2010-02.10.2010*. *Teilprojekt: Integrierte Siedlungswasserwirtschaft in den peri-urbanen Gergebieten von Darkhan, Mongolei*.

Senatsverwaltung für Stadtentwicklung und Umwelt Berlin. (2015). Rieselfelder Hobrechtsfelde. Retrieved April 11, 2015, from http://www.stadtentwicklung.berlin.de/forsten/rieselfelder_hobrechtsfelde/de/wandel1987.shtml

Siegl, A., & Löffler, H. (2008). Nutzen-Kosten-Bewertung dezentraler Abwasserbehandlung. *WWT-Special*, *6/2008*, 35–42.

Sigel, K. (2010). Environmental Sanitation in peri-urban Ger Areas in the City of Darkhan (Mongolia): a Description of current Status, Practices and Perceptions. *UFZ-Bericht*, (02/2010), 65. Report.

Sigel, K. (2012). *Urban Water Supply and Sanitation in Mongolia: a Description of the Political, Legal, and Institutional Framework*. *UFZ Discussion Papers*. Leipzig, Germany: Helmholtz-Zentrum für Umweltforschung GmbH (UFZ).

Sigel, K., Stäudel, J., & Londong, J. (2014). Experiences with stakeholder involvement in strategic sanitation planning: a case study of the city of Darkhan, Mongolia. *Water Science & Technology: Water Supply*, *14*(3), 504. http://doi.org/10.2166/ws.2014.001

Stäudel, J. (2008). *Stoffstromorientierte Abwassersysteme: Entwicklung stoffstromorientierter Konzepte für Abwassersysteme nach dem Vorbild ZERO EMISSION*. Saarbrücken, Germany: VDM Verlag Dr. Müller.

Stäudel, J., Khurelbaatar, G., Bruski, C., & Londong, J. (2012). The iPiT as Part of an Integrated

Sanitation System in Darkhan, Mongolia. *Poster Session, 2012 at WaSH Conference Organised by ACF on the 29th, 30th of March in Chinggis Hotel in Ulaanbaatar. Mongolia.* Poster, Ulaanbaatar, Mongolia. Retrieved from www.ipit.eu

Stäudel, J., Schalkwyk, B. Van, & Gibbens, M. (2014). Methods and strategies for community-based enhancement & up-scaling of sanitation & waste management in peri-urban areas in South Africa. In Bauhaus-Institut für zukunftsweisende Infrastruktursysteme (Ed.), *Schriftenreihe des Bauhaus-Instituts für zukunftsweisende Infrastruktursysteme (b.is)* (Vol. 15, pp. 31–50). Weimar: Rhombos-Verlag Berlin.

Steinmann, H., & Schreyögg, G. (2000). *Management - Grundlagen der Unternehmensführung: Konzepte - Funktionen - Fallstudien*. (Betriebswirtschaftlicher Verlag Dr. Th. Gabler GmbH, Ed.). Wiesbaden, Germany.

Strande, L., Ronteltap, M., & Brdjanovic, D. (2014). *Faecal Sludge Management: Systems Approach for Implementation and Operation*. London, UK: IWA Publishing.

Strell, M. (1913). *Die Abwasserfrage in ihrer geschichtlichen Entwicklung von den ältesten Zeiten bis zur Gegenwart.* Leipzig, Germany: Verlag von F. Leineweber.

Sugimoto, H., Kawagishi, U., Kitano, K., Gonchigbat, I., & Hirota, N. (2007). Living Environment of Nomads Residing on the Outskirts of Ulaanbaatar, Mongolia: Dispositional Characteristics from the Perspective of a Comparison of Nomads and People Living in Ger Fixed Residences in the City. *Journal of Asian Architecture and Building Engineering*, *6*(2), 283–290.

SuSanA. (2010). *Compilation of 31 Case Studies on Sustainable Sanitation Projects*. Eschborn, Germany: Sustainable Sanitation Alliance (SUSanA).

SuSanA. (2016a). Sanitation Case studies on SuSanA. Retrieved January 25, 2016, from http://www.susana.org/en/resources/case-studies

SuSanA. (2016b). Sustainable sanitation - the definition. Retrieved February 24, 2016, from http://www.susana.org/en/about/sustainable-sanitation

The World Bank. (2012). *What A Waste: A Global Review of Solid Waste Management* (Report). Washington D.C., USA.

The World Bank. (2016). The World Bank DataBank. Retrieved May 23, 2016, from http://databank.worldbank.org/data/home.aspx

Thomas Giese (Hrg.), & Jörg Londong (Hrg.). (2015). *Kopplung von regenerativer Energiegewinnung mit innovativer Stadtentwässerung: Synthesebericht zum Forschungsprojekt KREIS*. (T. Giese & J. Londong, Eds.), *Schriftenreihe des Bauhaus-Instituts für zukunftsweisende Infrastruktursysteme (b.is)* (Vol. 16). Weimar, Germany: Rhombos-Verlag Berlin.

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). *Compendium of Sanitation Systems and Technologies* (2nd Revise). Book, Dübendorf, Switzerland: Swiss Federal Institute of Aquatic Science and Technology (Eawag).

UBA. (2010). *Wasserwirtschaft in Deutschland - Teil 1: Grundlagen*. Dessau-Roßlau, Germany.

Uddin, S. M. N. (2015). *A Study on Sustainable Sanitation Technologies for Vulnerable Peri-Urban Communities in Ulaanbaatar, Mongolia*. ACF-INTERNATIONAL — USTB.

Ulrich, L. (2010). *Sustainable Sanitation Technologies for Peri-Urban Ger Areas in Mongolia* (Master Thesis; Presentation). Eidgenössische Technische Hochschule Zürich (ETH); Swiss Federal Institute of Technology Zurich, Dübendorf, Switzerland.

Ulrich, L. (2011). CLUES: Community-Led Urban Environmental Sanitation Planning. Poster, EAWAG: Swiss Federal Institute of Aquatic Science and Technology.

UN. (2015). *Transforming our world: The 2030 agenda for sustainable development A/RES/70/1. United Nations*. UN. http://doi.org/10.1007/s13398-014-0173-7.2

UNESCAP. (2010). *Public-Private Partnership Projects in Infrastructure*. Bangkok, Thailand: United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). http://doi.org/10.1017/CBO9780511974403

UNESCO. (2012). *The United Nations World Water Development Report 4: Managing Water under Uncertainty and Risk*. Paris.

UNICEF, & GIZ. (2013). *Field Guide: The Three Star Approach for WASH in Schools*. Eschborn, Germany.

United Nations. (2005a). *Progress towards the Millennium Development Goals, 1990-2002: GOAL 7 – Ensure environmental sustainability*. United Nations: United Nations. Retrieved from http://millenniumindicators.un.org/unsd/mdg/Resources/Attach/Products/Progress2005/goal_7.pdf

United Nations. (2005b). *The Millennium Development Goals Report 2005*. United Nations, United Nations: United Nations.

United Nations. (2014). *The Millennium Development Goals Report 2014*. United Nations: United Nations. Retrieved from http://mdgs.un.org/unsd/mdg/Host.aspx?Content=Indicators/OfficialList.htm

United Nations Millennium Declaration. (2008). Millennium Development Goals (MDGs) - Official list of MDG indicators. Retrieved July 29, 2014, from http://mdgs.un.org/unsd/mdg/Resources/Attach/Indicators/OfficialList2008.pdf

Vahs, D. (2001). *Organisation - Einführung in die Organistationstheorie und -praxis. Einführung in die Organisationstheorie und -praxis*. Stuttgart, Germany: Schäffer-Poeschel Verlag Stuttgart.

van der Vleuten-Balkema, A. J. (2003). *Sustainable wastewater treatment: developing a methodology and selecting promising systems*. Technische Universiteit Eindhoven, Eindhoven, Niederlande. Retrieved from http://w3.ieis.tue.nl/fileadmin/tm/TDO/Hora_Est.pdf#page=47

Virchow, R. (1868). *Ueber die Kanalisation von Berlin*. Berlin, Germany: Verlag von August Hirschwald.

Virchow, R. (1869). *Canalisation oder Abfuhr? Eine hygienische Studie*. Berlin, Germany: Verlag von Georg Reimer.

Vogt, A. (1873). *Ueber Städtereinigung und ein neues System ventilirter Latrinenfässer*. Bern, Switzerland: Commissions-Verlag von B. F. Haller.

Vries, F. W. T. P. De. (2006). Learning Alliances for the broad implementation of an integrated approach to multiple sources, multiple uses and multiple users of water. *Water Resources Management*, *21*(1), 79–95. http://doi.org/10.1007/s11269-006-9042-2

Weyl, T. (1897). *Handbuch der Hygiene*. (T. Weyl, Ed.) (Vol. 2). Jena, Germany: Verlag von Gustav Fischer.

Weyl, T. (1906). *Die Assanierung der Städte in Einzeldarstellungen: Erster Band. Paris - Wien - Zürich - Cöln*. (Herausgegeben im Verein mit Hygienikern und Ingenieuren des In- und Auslandes, Ed.), *Die Assanierung der Städte in Einzeldarstellungen* (Vol. Erster Ban). Leipzig, Germany: Verlag von Wilhelm Engelmann.

Weyl, T., Gerson, G. H., & Vogel, J. H. (1896). *Die Schicksale der Fäkalien in kanalisierten und nichkanalisierten Städten. Rieselfelder. Handbuch der Hygiene* (Vol. 2). Jena, Germany: Verlag von Gustav Fischer.

WHO. (1987). *Technology for water supply and sanitation in developing countries* (Technical Report Series) (Vol. 742). Geneva, Switzerland: World Health Organization.

WHO. (2015). WHO I Health Topics I Sanitation. Retrieved December 5, 2015, from http://www.who.int/topics/sanitation/en/

WHO/FAO. (2002). Food energy – methods of analysis and conversion factors. *Fao Food and Nutrition Paper*, *77*, 93. http://doi.org/ISSN 0254-4725

WHO and UNICEF. (2013). *Progress on Sanitation and Drinking-Water - 2013 Update*. Geneva, Switzerland: WHO Press.

WHO and UNICEF. (2015). *Progress on sanitation and drinking water – 2015 update and MDG assessment*. (UNICEF and World Health Organization 2015, Ed.), *Progress on sanitation and drinking water*. UNICEF and World Health Organization 2015.

Wikipedia. (2016). Ecological sanitation. Retrieved March 26, 2016, from https://en.wikipedia.org/wiki/Ecological_sanitation

Wilderer, P. A., & Paris, S. (2001). *Integrierte Ver- und Entsorgungssysteme für urbane Gebiete (Abschlussbericht)* (Abschlussbericht). Garching, Germany.

Winker, M., Stäudel, J., von Münch, E., & Londong, J. (2013). NASS-Tage in Eschborn: Neue Wasserinfrastrukturkonzepte in der Stadtplanung. *KA Korrespondenz Abwasser, Abfall*, *60*(8), 660–661. Bericht. Retrieved from www.dwa.de/KA

Wolter, S., Hiessl, H., & Hillenbrand, T. (2014). TWIST ++ Transitionswege WasserInfraSTruktursysteme. *KA Korrespondenz Abwasser Abfall*, *2014*(4), 273–275.

WSP. (2012). *Sanitation Marketing Lessons from Cambodia: A Market-Based Approach to Delivering Sanitation*. (D. Pedi, P. Kov, & S. Smets, Eds.), *Water and Sanitation Program: Field Note*. Phnom Penh, Cambodia. Retrieved from www.wsp.org

WSSCC. (2004). *Listening - To those working with communities in Africa, Asia, and Latin America to achieve the UN goals for water and sanitation*. Geneva, Switzerland: Water Supply and Sanitation Collaborative Council (WSSCC). Retrieved from http://www.wsscc.org/sites/default/files/publications/wsscc_listening_2004_en.pdf

YARA GmbH & Co. KG. (2012). Düngefibel. Dülmen, Germany: YARA GmbH & Co. KG. Retrieved from www.effizientduengen.de

Zehfuss, G. (1869). *Die Pneumatische Canalisation*. Frankfurt am Main, Germany: Verlag der F. Boselli'schen Buchhandlung.

Дархан хот — Википедиа нэвтэрхий толь. (2016). Retrieved May 31, 2016, from https://mn.wikipedia.org/wiki/%D0%94%D0%B0%D1%80%D1%85%D0%B0%D0%BD_%D1%85%D0%BE%D1%82#cite_note-3

H Annexe

H.1 Input variables for the iSaS model

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
1. basic input parameter							
residents	total number residents	IP_res_num_total	**100.000**	cap	100.000	variable	rounded based on offical data
	ratio apartments	IP_res_ratio_apart	**40%**	%	40%	variable	offical data from Darkhan
	ratio ger area	IP_res_ratio_ger	60%	%	60%	variable	calculated
	number residents apartments	IP_res_num_apart	40.000	cap	40.000	variable	calculated
	number residents Ger area	IP_res_num_ger	60.000	cap	60.000	variable	calculated
	number residents in average apartment bloc	IP_res_num_apart_bloc	77	cap/apartment bloc	77	variable	calculated: the number refers to a typical apartment bloc with two entrances and 5 floors, two sides. The number of families in one typical apartment bloc calculates to 5*2*2=20 families. The average HH size calculates : 77/20 families = **3.85 familiy size, which is roughly the 3.7 average familiy** of official data: see Sigel, K. 2010.
	mean household size	IP_res_mean_HH_size	**3,7**	cap/hh	3,7	constant	official statistical data. National Statistical Office of Mongolia. (2013). Mongolian Statistical Yearbook 2012, 2012, 460.
urban structure	total area	IP_urb_area_total	**34,0**	km2	34,0	constant	quantity survey based on Google Earth. own data evaluation
	apartment areas	IP_urb_apart_area	**3,37**	km2	3,37	constant	quantity survey based on Google Earth. own data evaluation
	average number of typical apartment blocs with 2 entrances, 5 floors per km2	IP_urb_apart_blocs_per_area	**154**	pcs/km2	154	constant	own data evaluation: the typical bloc with 2 entrances has been counted. all other types were counted as an equivalent to the typical bloc. quantity survey based on Google Earth
	total number of apartment blocs	IP_urb_apart_blocs_total	519	pcs	519	constant	calculated
	ger areas	IP_urb_ger_area	**12,53**	km2	12,53	constant	quantity survey based on Google Earth. own data evaluation
	ger area - bag7 fo calculation specific value sewer	IP_urb_ger_area_bag7	**1,22**	km2	1,22	constant	quantity survey based on Google Earth. own data evaluation
	population density apartment areas	IP_urb_apart_density	11.869	cap/km2	11.869	constant	calculated. own data evaluation
	population density ger areas	IP_urb_ger_density	4.789	cap/km2	4.789	constant	calculated. own data evaluation
	number of khashaas in ger areas	IP_urb_num_khashaa	**10.000**	pcs	10.000	constant	is equal to number of iPiTs. rounded based on official data
infrastructure	road network in Ger areas (average)	IP_infra_road_ger_per_area	**18,60**	km/km2	18,60	constant	own data evaluation based on areas and road lengths in Ger areas by using GoogleEarth
	total road network Ger areas	IP_infra_road_ger_total	233	km	233	constant	quantity survey based on Google Earth - needed for calculation transport
	number of khashaas per km road network in Ger area	IP_infra_khassha_per_km_road	43	pcs/km	43	constant	
	number of khashaas per km road network in Ger area	IP_infra_km_per_tour_in_ger_area	0,70	km/tour	0,70	constant	calculated based on data from Google Earth - needed for calculation of transport. Assumption: both sides of the road are built-up area. The culculated number is in the range of physical counts done with Google Earth
	mean distance from biogas plant to ger area - return trip for one collection tour	IP_infra_km_returntrip_WWTP_to_ger_area	**7,00**	km/tour	7,00	variable	the mean distance to the ger area is measured base on data from Google Earth from WWTP to centre of ger area. The mean return trip ist calculated here. Assumption: the ger area in the south-east of Darkhan is close to agricultural field and has a separate stroage for urine. Therefore the distance to the WWTP is not considered. own data evaluation
	existing separate sewer system - total length	IP_infra_exist_sewer_length	**94,7**	km	94,7	constant	about 60 km have ND of 150mm, about 12 km have ND 500mm or more according to BMBF. (2009). p. 151. The connection sewer from industrial area to Darkhan is estimated to 7.25 km. Due to uncertainty the 7.25 km are not substracted from the total.
	existing separate sewer system - main and side branch >ND150mm	IP_infra_exist_sewer_main_branch	32,6	km	32,6	constant	calculated. assumption: main branch is all pipes with diameter >ND150mm. BMBF. (2009).
	existing separate sewer system - side branch <= ND150mm	IP_infra_exist_sewer_side_branch	**60,0**	km	60,0	constant	according to BMBF. (2009). p. 151. diameter < ND150
	existing separate sewer system - pressure pipe	IP_infra_exist_sewer_pressure_pipe	**2,1**	km	2,1	constant	according to BMBF. (2009). p. 151, pipe diameter not specified.
	existing sewer - pumping stations	IP_infra_exist_pump	**2**	pcs	2	constant	according to BMBF. (2009). p. 151
	sewage pipeline main branch in km per km2 apartment area	IP_infra_exist_sewer_main_per_area	9,7	km/km2	9,7	constant	calculated. BMBF. (2009).
	sewage pipeline side branch in km per km2 per apartment area	IP_infra_exist_sewer_side_per_area	17,8	km/km2	17,8	constant	calculated. BMBF. (2009).
	sewer pipeline main branch >ND150, type1_apartment area_in km per km2 area	IP_infra_planned_sewer_main_side_type1_apart_per_area	0,0	km/km2	0,0	constant	type 1,2,3 are not specified for apartment areas. planning documents are not available
	sewer pipeline side branch >ND150, type2_apartment area_in km per km2 area	IP_infra_planned_sewer_side_type2_apart_per_area	0,0	km/km2	0,0	constant	type 1,2,3 are not specified for apartment areas. planning documents are not available
	sewer pipeline side branch <=ND150, type3_apartment area_in km per km2 area	IP_infra_planned_sewer_side_type3_apart_per_area	0,0	km/km2	0,0	constant	type 1,2,3 are not specified for apartment areas. planning documents are not available
	WWTP - minimum treatment capacity per hour	IP_infra_wwtp_treat_min_capacity	442	m3/h	442	constant	calculated. NOTE: the displayed value only expresses the minimum capacity based on water consumption and connected residents
	biogas plant - minimum digester capacity	IP_infra_biogas_digest_min_capacity	5.128	m3	5.128	constant	calculated. NOTE: the displayed value only expresses the minimum capacity based on per capita sludge production rate, faeces quantity, SRT 20d and connected residents in apartment (40,000) and ger areas (60,000)
agricultural area	within 20km range	IP_agri_area_inrange20km	**21.743**	ha	21.743	constant	quantity survey based on Google Earth. own data evaluation
	within 10km range	IP_agri_area_inrange10km	**12.666**	ha	12.666	constant	quantity survey based on Google Earth. own data evaluation
	mean transport distance to field	IP_agri_mean_trans_dist	7,3	km	7,3	variable	quantity survey based on Google Earth. own data evaluation

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
2. process parameter & assumptions for treatment (technical parameter)							
destruction rates, process parameter	COD destruction in % at 15d SRT in WWTP	TP_COD_destr_WWTP_15dSRT	44%	%	44%	variable	calculated after deduction of effluent load and based on assumption: 50% of COD will be destroyed, 50% accumulated and removed in sludge. calculated based on DWA. (2009)
	N destruction (denitrification) in % at 15d SRT in WWTP	TP_N_destr_WWTP_15dSRT	66%	%	66%	variable	calculated: 1 - TP_ratio_N_in_sludge_to_digester - TP_ratio_N_discharge_Kharaa
	COD destruction in % at 20d digestion time - biogas production	TP_COD_destr_digester	**65%**	%	65%	variable	preconditions: sludge is adequate for digestion: biological paramters, nutrient ratios, no inhibition of growth (e.g. toxicity, NH3-): Furthermore: SIMPLIFICATION: primary sludge and excess sludge are not differentiated, WWTP performs as specified! Metcalf & Eddy Inc. (2003). Bruski (2015), p. 78 &p. 117f
	N destruction in % at 20d digestion time - biogas production	TP_N_destr_biogas	**1%**	%	1%	variable	**0,1 - 5 % of biogas = N. average N 1%** according to Institut für Energetik und Umwelt gGmbH u. a.: Studie: Einspeisung von Biogas in das Erdgas- netz. Leipzig 2007. published in energie | wasser-praxis 11/2008
	specific sludge production per person and day (primary and secondary sludge)	TP_specific_sludge_production	**6,20**	L/cap/d	6,20	variable	specific values based on DWA. 2009, p. 218: primary+secondary sludge, SRT 15d, primary settlement 1,0h: 1.2 L + 5,0 L = 6.2 L/cap/d
ratios of MF, EF, MonF, general	maximum ratio of separated urine in apartment buildings	TP_ratio_urine_separate_apart_max	**30%**	%	30%	variable	this value is used to calculate the amount of urine coming from one apartment bloc with installed urine separation
	ratio of Q wastewater loss in sewage system	TP_ratio_WW_total_loss_sewer	**30%**	%	30%	variable	based on data from MoMo 2009 reserach project.
	ratio of Q wastewater discharge to Kharaa river	TP_ratio_WW_discharge_Kharaa	97,7%	%	97,7%	variable	calculated: 1 - (specific sludge production/water consumption): = 1 - (TP_specific_sludge_production/MF_water_cons_apart)
	ratio of Q wastewater in sludge to biogas plant	TP_ratio_WW_to_biogas_plant	2,3%	%	2,3%	variable	calculated: specific sludge production/water consumption: = TP_specific_sludge_production/MF_water_cons_apart
	ratio of Q dewatered sludge recirculated to WWTP	TP_ratio_Q_recirc_to_WWTP	**87,5%**	%	87,5%	variable	based on DWA. 2009. p. 230: sludge gets thickened and dewatered, **dried solid content of sludge = 35%. DWA. (2009)**
	ratio of Q stabilised sludge from digester - fertilizer production	TP_ratio_Q_fertilizer	12,5%	%	12,5%	variable	calculated: 1-TP_ratio_Q_recirc_to_WWTP, **dried solid content of sludge = 35%**
	treshold value COD effluent WWTP	TP_COD_treshold_WWTP_out	**75**	mg/L	75	constant	assumption: WWTP categorized as size range 5 (Größenklasse 5) according to German AbwV). DWA. (2009)
	treshold value total N effluent WWTP	TP_N_treshold_WWTP_out	**13**	mg/L	13	constant	assumption: WWTP categorized as size range 5 (Größenklasse 5) according to German AbwV). DWA. (2009)
	treshold value total P effluent WWTP	TP_P_treshold_WWTP_out	**1**	mg/L	1	constant	assumption: WWTP categorized as size range 5 (Größenklasse 5) according to German AbwV). DWA. (2009)
	ratio of COD removal in WWTP & discharge based on treshold load COD=75mg/L	TP_ratio_COD_discharge_Kharaa	12%	%	12%	variable	calculated: the ratio is calculated, so that the WWTP would always comply to the treshold values: it changes with changing water consumption and changing concentration: a safety factor of 50% is included in this calculation. calculated based on DWA. (2009)
	ratio of COD removal in WWTP by sludge to biogas plant	TP_ratio_COD_in_sludge_to_digest	44%	%	44%	variable	calculated based on DWA. (2009)
	ratio of COD recirculated from digester to WWTP	TP_ratio_COD_recirc_to_WWTP	10%	%	10%	variable	calculated: 1-TP_ratio_COD_fertilizer
	ratio of COD in stabilised sludge from digester - fertilizer production	TP_ratio_COD_fertilizer	**90%**	%	90%	variable	assumption based on Bruski, C 2015, p. 114
	ratio of N removal in WWTP & discharge based on treshold load N=13mg/L	TP_ratio_N_discharge_Kharaa	18%	%	18%	variable	calculated: the ratio is calculated, so that the WWTP would always comply to the treshold values: it changes with changing water consumption and changing concentration. safety factor of 50% is included in this calculation
	ratio of N removal in WWTP by sludge to biogas plant	TP_ratio_N_in_sludge_to_digester	**16%**	%	16%	variable	around 15% of the total load N gets incorporated in biomass according to ATV A131. (Note: The **dissolved** load of N in the sludge water to the biogas plant to the digester is between 1-2% of the total load., therefore 15%+1%=16% as removal ratio N to biogas digester)
	ratio of N recirculated from digester to WWTP	TP_ratio_N_recirc_to_WWTP	40%	%	40%	variable	calculated
	ratio of N in stabilised sludge from digester- fertilizer production	TP_ratio_N_fertilizer	**59%**	%	59%	variable	based on Bruski, C. (2015). p. 114
	ratio of P removal in WWTP & discharge based on treshold load P=1mg/L	TP_ratio_P_discharge_Kharaa	9%	%	9%	variable	calculated: the ratio is calculated, so that the WWTP would always comply to the treshold values: it changes with changing water consumption and changing concentration. safety factor of 50% is included in this calculation
	ratio of P removal in WWTP by sludge to biogas plant	TP_ratio_P_in_sludge_to_digester	91%	%	91%	variable	calculated
	ratio of P recirculated from digester to WWTP	TP_ratio_P_recirc_to_WWTP	8%	%	8%	variable	calculated
	ratio of P in stabilised sludge from digester- fertilizer production	TP_ratio_P_fertilizer	**92%**	%	92%	variable	based on Bruski, C. (2015). p. 114
	ratio of K removal in WWTP & discharge to Kharaa	TP_ratio_K_discharge_Kharaa	9%	%	9%	variable	calculated. assumption: chemical fate of K is similar to chemical fate of P
	ratio of K removal in WWTP by sludge to biogas plant	TP_ratio_K_in_sludge_to_digester	91%	%	91%	variable	calculated. assumption: chemical fate of K is similar to chemical fate of P
	ratio of K recirculated from digester to WWTP	TP_ratio_K_recirc_to_WWTP	8%	%	8%	variable	calculated. assumption: chemical fate of K is similar to chemical fate of P
	ratio of K in stabilised sludge from digester- fertilizer production	TP_ratio_K_fertilizer	92%	%	92%	variable	calculated. assumption: chemical fate of K is similar to chemical fate of P
transport services	emptying frequency urine container, size 60 l, weekly	TP_trans_empty_urine	**52**	times/year	52	constant	based on experience from the pilot project, the value has to be adapted according to conainer size, family member, background
	emptying frequency faeces container, size 60 l, every 4 weeks	TP_trans_empty_faeces	**13**	times/year	13	constant	based on experience from the pilot project, the value has to be adapted according to conainer size, family member, background

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
	emptying frequency separated urine in apartment blocs S1, annually	TP_trans_empty_urine_apart_S1	2	times/year	2	constant	system designed to achieve a bi-annual emptying frequency in the apartments
	No of collected container per tour (loading capacity small truck)	TP_trans_No_container_tour	30	pcs/tour	30	variable	based on loading capacity of KIA Bongo transporter in pilot project and economic evaluation of iPiT system
	No of tours of emptying urine storage S1 and transport to field per day	TP_trans_No_urine_storage_empty_d	14	times/d	14	variable	assumption
solids retention time	SRT in digester - $SRT_{digester}$	TP_SRT_digester	20	d	20	constant	preconditions: sludge is adequate for digestion: biological paramters, nutrient ratios, no inhibition of growth (e.g. toxicity, NH3-): Furthermore: SIMPLIFICATION: primary sludge and excess sludge are not differentiated, primary settling good, WWTP performs as specified! Metcalf & Eddy. 2003.
	SRT in WWTP_COD removal - $SRT_{WWTP, COD winter}$	TP_SRT_WWTP_COD_destr_winter	5	d	5	constant	estimations based on DWA. 2009, Tab 5.22, Metcalf & Eddy. 2003.
	SRT in WWTP_COD removal - $SRT_{WWTP, COD summer}$	TP_SRT_WWTP_COD_destr_summer	5	d	5	constant	estimations based on DWA. 2009, Tab 5.22, Metcalf & Eddy. 2003.
	SRT in WWTP_denitrification - $SRT_{WWTP, deni, winter}$	TP_SRT_WWTP_deni_winter	15	d	15	constant	estimations based on DWA. 2009, Tab 5.22, Metcalf & Eddy. 2003.
temperatures	temperature outside summer - average	TP_T_outside_summer	18	°C	18	constant	data from pilot project
	temperature outside winter - average	TP_T_outside_winter	-25	°C	-25	constant	data from pilot project
	temperature wastewater summer	TP_T_WW_summer	12	°C	12	constant	data from pilot project
	temperature wastewater winter	TP_T_WW_winter	8	°C	8	constant	data from pilot project
safety factor	safety factor for operation of WWTP & compliance of treshold values	TP_safety_WWTP_treshold	1,5		1,5	constant	safety factor for operation of WWTP and compliance of treshold values
fertilizer application	application rate fertilizer per 1 MG expected yield **wheat** (winter) grain - **N**	TP_agri_wheat_yield1Mg_kgN_per_ha	19	kg/ha/Mg yield wheat grain	19	constant	the values are taken from an iOS app of IPNI. it is assumend, that the yield is approximately linear within the range of common agricultral practice. The apps and other sources like http://www.effizientduengen.de show a linaear behaviour. Wheat is the main crop produced around Darkhan. International Plant Nutrition Institute IPNI. 2014. www.ipni.info
	application rate fertilizer per 1 MG expected yield **wheat** (winter) grain - **P**	TP_agri_wheat_yield1Mg_kgP_per_ha	3,5	kg/ha/Mg yield wheat grain	3,5	constant	the values are taken from an iOS app of IPNI. it is assumend, that the yield is approximately linear within the range of common agricultral practice. The apps and other sources like http://www.effizientduengen.de show a linaear behaviour. Wheat is the main crop produced around Darkhan. International Plant Nutrition Institute IPNI. 2014. www.ipni.info
	application rate fertilizer per 1 MG expected yield **wheat** (winter) grain - **K**	TP_agri_wheat_yield1Mg_kgK_per_ha	4	kg/ha/Mg yield wheat grain	4	constant	the values are taken from an iOS app of IPNI. it is assumend, that the yield is approximately linear within the range of common agricultral practice. The apps and other sources like http://www.effizientduengen.de show a linaear behaviour. Wheat is the main crop produced around Darkhan. International Plant Nutrition Institute IPNI. 2014. www.ipni.info
	application rate fertilizer in agriculture - **N**	TP_agri_app_rate_N_per_ha	65	(kgN)/ha/a	65	variable	The average yield of wheat in Mongolia was roughly 6 times lower, compared to Germany in 2014. Typical application rates in Germany are in a range of 135 to 230 kgN/ha for 8-9 Mg yield/ha. Considering the short vwgetation period a lower value should be set, in order to reveal a realistic result.
	application rate fertilizer in agriculture - **P**	TP_agri_app_rate_P_per_ha	12,0	(kgP)/ha/a	12,0	variable	The average yield of wheat in Mongolia was roughly 6 times lower, compared to Germany in 2014. Typical application rates in Germany are in a range of 135 to 230 kgN/ha for 8-9 Mg yield/ha. Considering the short vegetation period a lower value should be set, in order to reveal a realistic result. As P accumulates in the soil and application rates need to be determined location-based, the values are put in a ratio to the application rates of N above
	application rate fertilizer in agriculture - **K**	TP_agri_app_rate_K_per_ha	13,7	(kgK)/ha/a	13,7	variable	The average yield of wheat in Mongolia was roughly 6 times lower, compared to Germany in 2014. Typical application rates in Germany are in a range of 135 to 230 kgN/ha for 8-9 Mg yield/ha. Considering the short vegetation period a lower value should be set, in order to reveal a realistic result. As K accumulates in the soil and application rates need to be determined location-based, the values are put in a ratio to the application rates of N above
3. material-flows							
water consumption	water consumption in apartments	MF_water_cons_apart	265	l/cap/d	265	variable	NOTE: in BMBF. (2009). the mean water consumption is set as basis for wastewater discharge (p.151). However, in reality the wastewater discharge is always lower, related to the consumption. Further on a 40% loss of water in the DW network is described, but not applied here. Therefore in the model the stated value for consumption is set as input value. rounded based on official data.
	water consumption in ger areas	MF_water_cons_ger	12	l/cap/d	12	variable	data from pilot project. rounded based on official data
urine	Q	MF_urine_Q	1,37	l/(cap*d)	1,37	constant	compiled from DWA. (2015)
	TS	MF_urine_TS	57	g/(cap*d)	57	constant	compiled from DWA. (2015)
	TVS	MF_urine_TVS	41	g/(cap*d)	41	constant	compiled from DWA. (2015)
	BOD_5	MF_urine_BOD	5	g/(cap*d)	5	constant	compiled from DWA. (2015)
	COD	MF_urine_COD	10	g/(cap*d)	10	constant	compiled from DWA. (2015)
	N	MF_urine_N	10,4	g/(cap*d)	10,4	constant	compiled from DWA. (2015)
	P	MF_urine_P	1,0	g/(cap*d)	1,0	constant	compiled from DWA. (2015)
	K	MF_urine_K	2,5	g/(cap*d)	2,5	constant	compiled from DWA. (2015)
faeces	Q	MF_faeces_Q	0,14	l/(cap*d)	0,14	constant	compiled from DWA. (2015)

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
	TS	MF_faeces_TS	**38**	g/(cap*d)	38	constant	compiled from DWA. (2015)
	TVS	MF_faeces_TVS	**35**	g/(cap*d)	35	constant	compiled from DWA. (2015)
	BOD_5	MF_faeces_BOD	**20**	g/(cap*d)	20	constant	compiled from DWA. (2015)
	COD	**MF_faeces_COD**	**60**	g/(cap*d)	60	constant	compiled from DWA. (2015)
	N	**MF_faeces_N**	**1,5**	g/(cap*d)	1,5	constant	compiled from DWA. (2015)
	P	**MF_faeces_P**	**0,5**	g/(cap*d)	0,5	constant	compiled from DWA. (2015)
	K	**MF_faeces_K**	**0,7**	g/(cap*d)	0,7	constant	compiled from DWA. (2015)
greywater Ger area	Q	**MF_grey_Q_ger**	12	l/(cap*d)	12	constant	calculated. based on water consumption in Ger area. compiled from DWA. (2015)
	TS	MF_grey_TS	**71**	g/(cap*d)	71	constant	compiled from DWA. (2015)
	TVS	MF_grey_TVS	**44**	g/(cap*d)	44	constant	compiled from DWA. (2015)
	BOD_5	MF_grey_BOD	**18**	g/(cap*d)	18	constant	compiled from DWA. (2015)
	COD	**MF_grey_COD**	**47**	g/(cap*d)	47	constant	compiled from DWA. (2015)
	N	**MF_grey_N**	**1,0**	g/(cap*d)	1,0	constant	compiled from DWA. (2015)
	P	**MF_grey_P**	**0,5**	g/(cap*d)	0,5	constant	compiled from DWA. (2015)
	K	**MF_grey_K**	**1,0**	g/(cap*d)	1,0	constant	compiled from DWA. (2015)
wastewater apartment	Q	**MF_wastewater_Q**	265	l/(cap*d)	265	constant	calculated based on MF urine, faeces, greywater and water consumption. calculated based on DWA. (2015).
	TS	MF_wastewater_TS	166	g/(cap*d)	166	constant	calculated based on MF urine, faeces, greywater and water consumption. **ATTENTION:** values differ from standard values of raw wastewater, presumably these include industrial wastewater related on PE. calculated based on DWA. (2015).
	TVS	MF_wastewater_TVS	120	g/(cap*d)	120	constant	calculated based on MF urine, faeces, greywater and water consumption. **ATTENTION:** values differ from standard values of raw wastewater, presumably these include industrial wastewater related on PE. calculated based on DWA. (2015).
	BOD_5	MF_wastewater_BOD	43	g/(cap*d)	43	constant	calculated based on MF urine, faeces, greywater and water consumption. calculated based on DWA. (2015).
	COD	**MF_wastewater_COD**	117	g/(cap*d)	117	constant	calculated based on MF urine, faeces, greywater and water consumption. calculated based on DWA. (2015).
	COD - load in mg/L	MF_wastewater_COD_load	442	mg/L	442	constant	calculated based on MF urine, faeces, greywater and water consumption, the load is used to calcute the discharge ratio in order to comply with the limits of the treshold of effluent from WWTP. calculated based on DWA. (2015).
	N	**MF_wastewater_N**	13	g/(cap*d)	13	constant	calculated based on MF urine, faeces, greywater and water consumption. calculated based on DWA. (2015).
	N - load in mg/L	MF_wastewater_N_load	49	mg/L	49	constant	calculated based on MF urine, faeces, greywater and water consumption, the load is used to calcute the discharge ratio in order to comply with the limits of the treshold of effluent from WWTP. calculated based on DWA. (2015).
	P	**MF_wastewater_P**	2	g/(cap*d)	2	constant	calculated based on MF urine, faeces, greywater and water consumption. calculated based on DWA. (2015).
	P - load in mg/L	MF_wastewater_P_load	8	mg/L	8	constant	calculated based on MF urine, faeces, greywater and water consumption, the load is used to calcute the discharge ratio in order to comply with the limits of the treshold of effluent from WWTP. calculated based on DWA. (2015).
	K	**MF_wastewater_K**	4	g/(cap*d)	4	constant	calculated based on MF urine, faeces, greywater and water consumption. calculated based on DWA. (2015).
	K - load in mg/L	MF_wastewater_K_load	16	mg/L	16	constant	calculated based on MF urine, faeces, greywater and water consumption, the load is used to calcute the discharge ratio in order to comply with the limits of the treshold of effluent from WWTP. calculated based on DWA. (2015).
solid waste	Q_mass_ger areas in summer	MF_swaste_Qmass	**172**	g/(cap*d)	172	constant	this data was collected in August 2012 by BUW, not representative, high difference in winter due to ash from burning coal. Böhm, M. (2013)
	density solid waste ger area summer	MF_swaste_density	**200**	g/l	200	constant	this data was collected in August 2012 by BUW. Böhm, M. (2013)
biowaste	biowaste mass % - 25 % of Q_mass_ger	MF_biowaste_ratio	**25%**	%	25%	constant	this data was collected in August 2012 by BUW. Böhm, M. (2013)
	Q_biowaste_mass_ger areas in summer	**MF_biowaste_Qmass**	43	g/(cap*d)	43	constant	this data was collected in August 2012 by BUW. Böhm, M. (2013)
	Q_biowaste_dry matter = 19.65% of organic mass (TS)	MF_biowaste_TS	8	g/(cap*d)	8	constant	this data was collected in August 2012 by BUW (Dry matter (DM) is that which remains after redrying at 105°C for 15h a previously dried and ground sample. Böhm, M. (2013)
	TVS (loss on ignition) - 76% of TS	MF_biowaste_TVS	6,4	g/(cap*d)	6,4	constant	this data was collected in August 2012 by BUW (Organic Matter is the loss in weight of DM after 15h at 550°C expressed as a percentage of DM). Böhm, M. (2013)
	TOC_organic waste =0.51*TVS+0.48	MF_biowaste_TOC	3,8	g/(cap*d)	3,8	constant	value calculated based on : TOC=0.51*TVS+0.48 and **COD/TOC=3.35** (mean value ratio for raw wastewater: COD/TOC is in a range of 3.2-3.5: see Tabelle 3.4. DWA. (2009), Table 3.4; Navarro et al. (1993)
	BOD_5	MF_biowaste_BOD	51	g/(cap*d)	51	constant	value calculated based on : TOC=0.51*TVS+0.48 and **COD/TOC=3.35** (mean value ratio for raw wastewater: COD/TOC is in a range of 3.2-3.5: see Tabelle 3.4. DWA. (2009), Table 3.4; Navarro et al. (1993)
	COD	**MF_biowaste_COD**	12,6	g/(cap*d)	12,6	constant	value calculated based on : TOC=0.51*TVS+0.48 and **COD/TOC=3.35** (mean value ratio for raw wastewater: COD/TOC is in a range of 3.2-3.5: see Tabelle 3.4. DWA. (2009), Table 3.4; Navarro et al. (1993)
	N (mean value: 1.65% of TS)	**MF_biowaste_N**	0,14	g/(cap*d)	0,14	constant	value calculated as mean from range_min and range_max * MF_biowaste_TS. Ottow, J. C. G., et al. (1997)
	P (mean value: 0.40% of TS)	**MF_biowaste_P**	0,03	g/(cap*d)	0,03	constant	value calculated as mean from range_min and range_max * MF_biowaste_TS. Ottow, J. C. G., et al. (1997)
	K (mean value: 0.88% of TS)	**MF_biowaste_K**	0,07	g/(cap*d)	0,07	constant	value calculated as mean from range_min and range_max * MF_biowaste_TS. Ottow, J. C. G., et al. (1997)

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
4. energy-flows							
biogas	methane NL - production	EF_methane_TOC_P	**1,81**	NL/(gTOC)	1,81	constant	Scherer, P. (2008)
	biogas NL - production per g TVS	EF_biogas_TVS_P	**408**	NL/(kgTVS)	408	constant	preconditions: sludge is adequate for digestion: biological paramters, nutrient ratios, no inhibition of growth (e.g. toxicity, NH3-): Furthermore: SIMPLIFICATION: primary sludge and excess sludge are not differentiated, primary settling good, WWTP performs as specified! NOTE: the specific gas production is depending on the substrate. In the Darkhan case the specific value for faeces is almost 60% higher compared to the primary sludge and based on TVS (German: oTR). DWA. (2009), Table 8.22, p. 264
	biogas NL - production per g COD	EF_biogas_COD_P	771	NL/(kgCOD)	771	constant	**calculated:** the specfic biogas production TVS is related to COD based on the findings of C.Bruski, p. 114: **COD/TVS**=25.96/13.73=**1.89** NOTE: the specific gas production is depending on the substrate. In the Darkhan case the specific value for faeces is almost 60% higher compared to the primary sludge and based on TVS (German: oTR). DWA. (2009), Table 8.22, p. 264
	biogas NL - production - specific value per capita, sedimentation time >1h, SRT = 15d	EF_biogas_per_capita_P	**18,2**	NL/(cap*d)	18,2	constant	NOTE: the specific gas production is depending on the substrate. In the Darkhan case the specific value for faeces is almost 60% higher compared to the primary sludge and based on TVS (German: oTR). DWA. (2009), Table 8.22, p. 264
fuel	fuel consumption transport Ger area	EF_fuel_consum_ger_C	**12**	L/100km	12	constant	assumption for pick-up trucks
	fuel consumption transport storage / farmland	EF_fuel_consum_agri_C	**12**	L/100km	12	constant	assumption
heat	biogas NL - heat value per Nm3 biogas - production	EF_heat_value_biogas_P	**6,5**	kWh/Nm3	6,5	constant	DWA. (2009). p. 262
	biogas plant - conditioning building - heat comsumption - conditioning substrate - in January at -25°C - consumption	EF_heat_biogas_condit_C	**0,00577**	kWh/(cap*d)	0,00577	constant	Bruski, C. (2015), p. 103. specific heat consumption of conditioning hall. based on a biogas digester suitable for 100,000 residents and co-digestion of faeces and excess sludge
	biogas plant - conditioning building - thawing of faeces - in January at -25°C - consumption	EF_heat_biogas_thawing_faeces_C	**0,02385**	kWh/(cap*d)	0,02385	constant	Bruski, C. (2015), p. 100. specific value for thawing faeces in January. based on a biogas digester suitable for 100,000 residents and co-digestion of faeces and excess sludge.
	biogas plant - digester - max heat loss in January at -25°C - consumption	EF_heat_biogas_process_C	**0,00079**	kWh/(cap*d)	0,00079	constant	Bruski, C. (2015), p. 102. specific heat loss value for the digester in Darkhan in January. based on a biogas digester suitable for 100,000 residents and co-digestion of faeces and excess sludge.
	biogas plant - digester - heat recovery from sludge	EF_heat_recovery_biogas_process_P	**0,00186**	kWh/(cap*d)	0,00186	constant	Bruski, C. (2015), p. 105.
	biogas plant - CHP - heat production from biogas - production	EF_heat_biogas_CHP_P	**0,02921**	kWh/(cap*d)	0,02921	constant	Bruski, C. (2015), p. 104. assumption: **heat efficiency CHP η = 50%**
electricity	Sewage system - pumping station - consumption	EF_elec_sew_pump_C	0	kWh	0	constant	to be verified
	WWTP - pumping station - consumption	EF_elec_WWTP_pump_C	0	kWh	0	constant	to be verified
	WWTP - aeration acitvated sludge process - consumption	EF_elec_WWTP_oxygen_C	0	kWh	0	constant	to be verified
	WWTP - other - consumption	EF_elec_WWTP_total_C	0	kWh/PE/a	0	constant	to be verified
	biogas plant - electritcity production per L biogas - production	EF_elec_biogas_P	0	kWh/PE/a	0	constant	to be verified
	biogas plant - electricity - consumption	EF_elec_biogas_C	0	kWh	0	constant	to be verified
	WWTP - electricity consumption per PE and year - consumption	EF_elec_WWTP_total_per_PE_C	**25**	kWh/PE/a	0	constant	specific value from Germany, slightly increased to fit Mongolian circumstance. Halbach. (2003). p. 71
	biogas plant - electritcity production per L biogas - production	EF_elec_biogas_faeces_per_PE_P	7,5	kWh/PE/a	0	constant	calculated based on findings from C. Bruski (2015). p. 104, 114
5. monetary-flows							
commercial value NPK	N	MonF_N	**0,89**	€/kg	0,89	variable	based on data from the Worldbank Databank
	P	MonF_P	**1,81**	€/kg	1,81	variable	based on data from the Worldbank Databank
	K	MonF_K	**0,67**	€/kg	0,67	variable	based on data from the Worldbank Databank
electricity	electricity large consumer tariff	MonF_elec	**0,061**	€/kWh	0,061	variable	130 MNT/kWh on 28.06.2016, exchange rate 1MNT = 0.00047€, 1€ = 2128MNT
heating	central heating supply	MonF_heat	**0,216**	€/m2m	0,216	variable	460 MNT/m2 and month on 28.06.2016, exchange rate 1MNT = 0.00047€. 1€ = 2128MNT
fuel	fuel cost transport	MonF_fuel_transport	**0,806**	€/L	0,806	variable	Average 1720MNT/l (1550-1890 MNT/l) on 28.06.2016, exchange rate 1MNT = 0.00047€, 1€ = 2128MNT. standard for model: 0.806 €/L
investment costs	planning costs, detailied design, supervision of implementation in % of total investment costs	MonF_invest_consultant	**15%**	%	15%	constant	**10% of total investment costs is a usual value. Due to complexity of iSaS a higher value is reasonable**
	planning costs, detailied design, supervision of implementation in % of total investment costs	MonF_invest_consultant_WWS	**10%**	%	10%	constant	**10% of total investment costs is a usual value.**
	planning costs, detailied design, supervision of implementation in % of total investment costs	MonF_invest_consultant_S1	**2%**	%	2%	constant	**planning effort for this scenario is low, therefore reduced planning costs**
	iPiT®	MonF_invest_ipit	**710**	€/pcs	710	variable	**710€ (exchange rate 01.01.2012: 1 € = 1775 MNT) for single unit production. Mass production should half the costs (assumption). BIG UNCERTAINTY !!! Exchang rate of 09.2016 would be less than 500€ !!! (exchange rate 01-09.2016: 1 € = 2488 MNT)**
	greywater trickling filter - sink whole	MonF_invest_greywater_filter	**50**	€/pcs	50	variable	assumption
	transport truck	MonF_invest_truck	**20.000**	€/pcs	20.000	constant	assumption

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
	workshop for transport system / equipment / others	MonF_invest_iSaS_equipment	**200.000**	€/pcs	200.000	constant	assumption
	urine storage tanc for collected urine from ger areas	MonF_invest_urine_storage	**582.000**	€	582.000	constant	assumption: the price has been estimated: 60,000 people in ger areas produce roughly 30,000m3 urine per year. urine will be used as fertilizer and applied in spring and autumn. this requires a storage quantity of 15,000 m3 at 3 different locations near the agricultural fields, where the urine can be applied. The detailed description of the estimation is shown in the dissertation, chapter D.
	urine storage tanc 18m3 for apartment blocs	MonF_invest_urine_storage_apart_S1	**10.000**	€	10.000	constant	one complete installation for 3 connected apartment blocs including 200m connection pipe and ventilation: assumption: 20000L GFK-Tank costs approx 7500€ in Germany, plus installation costs. see http://www.mosertankshop.de
	waterless urinals in apartment blocs	MonF_invest_urinal_apart_S1	**300**	€/pcs	300		cheapest waterless urinal in Germany starts at 230€ (Keramak Renova 1). the baseline price includs installation
	storage / conditioning area for faeces	MonF_invest_faeces_conditioning	**300.000**	€/pcs	300.000	constant	assumption
	bin cleaning machine	MonF_invest_bin_cleaning	**100.000**	€/pcs	100.000	constant	assumption: bin cleaning machine from Feistmantl or simliar, adjusted to fit to iPiT® collection bins.
	biogas plant	MonF_invest_biogas	**1.000.000**	€/pcs	1.000.000	constant	assumption
	WWTP reconstruction	MonF_invest_WWTP_new	**30.000.000**	€/pcs	########	constant	assumption: based on oral informationf from Mongolia
	total investment costs WWS in bag7 based on preliminary design	MonF_invest_WWS_bag7_total	**7.000.000**	€	7.000.000	constant	**total average investment costs based on preliminray design and tendering process in Darkhan from April-July 2013 for bag 7 was 14.3 Billion €**. The price needs to be verified, as regular tender processes were relatively unknown in Mongolia in 2013. Further on with the economic crisis in Mongolia the price in MNT is exchaged on an exchange rate of 29.03.2013, which marks the theoretical end of the tender process (1€=1781MNT). **The construction of new WCs in all khashaas in ger areas is not included. A corrected, modified price for sewage system ONLY of approx 12.5 Billion MNT or 7,000,00 Million € is included here.**
	investment cost WWS in ger area related to km2 based on total investment costs in bag7	MonF_invest_WWS_ger_per_area	5.737.705	€/km2	5.737.705	constant	**calculated. the price is specific per area Ger area and is based on price level from 03.2013 and includes different pipeline diameteres, excavation, installation, pumping station, pressure pipes, house connections**
	investment cost in a DWWS for ger area - estimated in % of investment costs	MonF_invest_DWWS_ratio_of_WWS	**20%**	%	20%	variable	**assumption:** the ratio in form of % of the investment costs is a rough estimation. actuall and reliable data for Mongolia is not available. **this value needs to be verified.**
	investment cost WWS in ger area related to km2 based on total investment costs in bag7	MonF_invest_DWWS_ger_per_area	1.147.541	€/km2	1.147.541	constant	calculated based on : MonF_invest_WWS_ger_per_area * MonF_invest_DWSS_ratio_of_WWS
	heated WC / bathroom Ger area	MonF_invest_house_toilet	**1.900**	€/pcs	1.900	constant	assumption: this value needs to be verified
economic lifetime	economic lifetime - iPiT® and greywater filter	MonF_lifeT_ipit	**10**	a	10	constant	assumption: economic lifetime of iPiT and greywater filter is equal
	economic lifetime - transport trucks	MonF_lifeT_truck	**10**	a	10	constant	assumption
	economic lifetime - workshop and equipment	MonF_lifeT_iSaS_equipment	**30**	a	30	constant	assumption
	economic lifetime - urine storage tanc	MonF_lifeT_urine_storage	**30**	a	30	constant	assumption
	economic lifetime iSaS - least common multiple	MonF_lifeT_iSaS_lcm	30	a	30	variable	calculation
	economic lifetime scenario S1 - urine storage tanc	MonF_lifeT_S1_urine_storage	**30**	a	30	constant	assumption
	economic lifetime scenario S1 - urinals	MonF_lifeT_S1_urinals	**15**	a	15	constant	assumption
	economic lifetime scenario S1 - least common multiple	MonF_lifeT_S1_lcm	30	a	30	variable	calculation
	economic lifetime wastewater system (canal)	MonF_lifeT_WWS	**60**	a	60	constant	assumption
	economic lifetime installation for urine separation - scenario 1	MonF_lifeT_apart_s1	**30**	a	30	variable	assumption
	economic lifetime equipment conventional WWS (pumps, compressor, aerator etc)	MonF_lifeT_WWS_equipment	**15**	a	15	variable	assumption
	economic lifetime of WC in ger area	MonF_lifeT_WC_ger_area	**60**	a	60	variable	assumption: residents would be self-responsible to maintaine and reinvest into their bathroom
	economic lifetime WWTP	MonF_lifeT_WWTP	**60**	a	60	variable	assumption
	economic lifetime WWS - least common multiple	MonF_lifeT_WWS_lcm	60	a	60	variable	calculation
costs O&M	salary	MonF_OM_salary	**3.700**	€/a	3.700	variable	**assumption: salary 900,000 MNT/m. NEEDS TO BE VERIFIED according to economical development: 2016 in Mongolia recession and economical crisis**
	number of working days in Mongolia	MonF_OM_working_days	**250**	No.	250	constant	based on experiences from Germany
	number of collection tours iSaS per team and day	MonF_OM_tour_number	**8**	No.	8	constant	based on experiences from pilot project
	number of staff per team	MonF_OM_staff_per_team	**3**	No.	3	constant	based on experiences from pilot project
	factor to include number of administrative and other technical staff iSaS	MonF_OM_staff_overhead_iSaS	**1,5**		1,5	variable	based on experiences from Germany, simplified: According to Halbach (2003) the costs for administration are linear in the here specfied range of residents.
	maintenance cost for iPiTs in % of investment costs	MonF_OM_ipit	**1,5%**	% / annual invest costs	1,5%	variable	typical assumption for annual maintenance costs in Germany for wastewater systems is 0.6% of the investment costs (Halbach.2003.). Due to extreme climate and exposure it is assumed, that this ratio is much higher in Mongolia. Resident can contribute to mitigate high costs.
	maintenance cost for transport system in % of investment costs	MonF_OM_transport	**5,0%**	% / annual invest costs	5,0%	variable	typical assumption for annual maintenance costs in Germany for wastewater systems is 0.6% of the investment costs (Halbach.2003.). Due to extreme climate and exposure it is assumed, that this ratio is much higher in Mongolia.

category	list of input parameters - iSaS model	name_variable	value	unit	baseline value	attribute	assumption / description / source
	rental of 10m3 truck for emptying of urine storage in apartment areas S1 per day of use incl staff	MonF_OM_transport_S1	160	€/d	160	variable	assumption of rental cost
	maintenance cost for iSaS equipment and urine storage in % of investment costs	MonF_OM_equipment	2,0%	% / annual invest costs	2,0%	variable	typical assumption for annual maintenance costs in Germany for wastewater systems is 0.6% of the investment costs (Halbach.2003.). Due to extreme climate and exposure it is assumed, that this ratio is much higher in Mongolia.
	maintenance cost for S1 equipment and urine storage in % of investment costs	MonF_OM_equipment_S1	1,0%	% / annual invest costs	1,0%	variable	typical assumption for annual maintenance costs in Germany for wastewater systems is 0.6% of the investment costs (Halbach.2003.). Due to extreme climate and exposure it is assumed, that this ratio is much higher in Mongolia: only the urine tancs need maintenance and the connection pipes. The urinals in the apartments are within the responsibility of the user.
	running costs biogas plant	MonF_OM_biogas	1,0%	% / annual invest costs	1,0%	variable	0.6% per annum of investment costs (Halbach. 2003). Due to extreme climate this value is assumed to be higher.
	running costs WWTP	MonF_OM_WWTP	1,0%	% / annual invest costs	1,0%	variable	0.6% per annum of investment costs (Halbach. 2003). Due to extreme climate this value is assumed to be higher.
	running costs sewage system	MonF_OM_WWS	1,0%	% / annual invest costs	1,0%	variable	0.6% per annum of investment costs (Halbach. 2003). Due to extreme climate this value is assumed to be higher.
	capacity development restructuring, marketing, public relations, fee calculation	MonF_OM_CD	2.500	€/a	2.500	variable	assumption, lump sum price
cost recovery	willingness-to-pay in ger areas per HH	MonF_cost_recovery_ger_HH	40	€/(**HH***a)	40	variable	assumption, based on (Gutjahr F. 2013): a study from 2011 stated, that the willingness to pay among residents would be approx. 6,000 MNT per family. (=3.34€ based on exchange rate of 29.03.2013 (1€=1781MNT)). **ASSUMPTION: one family = one HH**
	willingness-to-pay in ger areas per PE	MonF_cost_recovery_ger_PE	11,0	€/(PE*a)	11	variable	calculated: PE = person equivalent: MonF_cost_recovery_apart_HH / IP_res_mena_HH_size
	wastewater fee in apartment areas per HH	MonF_cost_recovery_apart_HH	50	€/(HH*a)	50	variable	assumption, based on (Gutjahr F. 2013): a study from 2011 stated, that the willingness to pay among residents would be approx. 6,000 MNT per family. (=3.34€ based on exchange rate of 29.03.2013 (1€=1781MNT)) **ASSUMPTION: one family = one HH**
	wastewater fee in apartment areas per PE	MonF_cost_recovery_apart_PE	14	€/(PE*a)	14	variable	calculated: PE = person equivalent: MonF_cost_recovery_apart_HH / IP_res_mena_HH_size

H.2 Source material, documents, further reading

Source material and documents:

An extensive amount of material, raw data and related documents has been collected during the pilot project phase in Mongolia and beyond. The material includes:

- maps
- monitoring data and evaluations
- technical drawings, tender documents and price lists
- contracts in English and Mongolian language
- documents for capacity development in English and Mongolian language
- design studies of iPiT
- photos and videos

and can be made accessible upon request.

Internet and further reading:

iPiT®-Website:
website of the part-project on integrated sanitation of the BUW: www.ipit.eu

KREIS-Website:
website of the research project "*KREIS – Supply through disposal*": http://kreis-jenfeld.de

SuSanA-Website:
website of the Sustainable Sanitation Alliance: www.susana.org

TWIST++ Website:
website of the research project "*TWIST – Transitionswege WasserInfraSTruktursysteme*": http://www.twistplusplus.de

List of student thesis compiled under the supervision of J. Stäudel:

Böhm, M., Lauckner, M., & Seyfarth, R. (2013). Development of an Integrated Solid Waste Management System: Recommendations for the Ger-Settlement Bag7 in Darkhan, Mongolia. Bauhaus-Universität Weimar, Weimar, Germany. (Project documentation).

Braun, C. (2014). Plausibility check of submitted documents in a tender process for a sewage system in Bag 7, Darkhan, Mongolia. Bauhaus-Universität Weimar, Weimar, Germany. (Study thesis).

Deicke, F. (2013). Alternative fertilization with the value-added reuse of products from treated feces & urine and their potentials for soils of the agricultural sector in the region of Darkhan, northern Mongolia. Bauhaus-Universität Weimar, Weimar, Germany. (Study thesis).

Feldmann, U. (2013). Ermittlung des weltweiten Verbreitungspotentials eines stoffstrom-basierten, integrierten Sanitärsystems basierend auf iPiT®, angepasster Behandlung und gewinnbringender Verwertung organischer Reststoffe. Bauhaus-Universität Weimar, Weimar, Germany. (Bachelor thesis).

Gutjahr, F. (2013). Entwicklung von angepassten Gebührensystemen für integrierte Sanitärsysteme in Jurtensiedlungen in der Mongolei. Bauhaus-Universität Weimar, Weimar, Germany. (Bachelor thesis).

Jossa, P. (2011). Aufbau und Betrieb einer häuslichen Toilettenanlage mit Stoffstromtrennung als zentraler Bestandteil eines integrativen Sanitärsystems für Jurten-Siedlungen in der Stadt Darkhan, nördliche Mongolei. Bauhaus-Universität Weimar, Weimar, Germany. (Bachelor thesis).

Lauckner, M. (2013). Implementierung einer thermischen Abfallbehandlungsanlage. Bauhaus-Universität Weimar, Weimar, Germany. (Master thesis).

Riechmann, M. (2013). Identifikation und Beschreibung der Kernelemente eines funktionalen Designs eines leitungsungebundenen, stoffstrombasierten Sanitärsystems anhand der iPiT®. Bauhaus-Universität Weimar, Weimar. (Bachelor thesis).

Schirmer, T. (2012). Description of Possibilities to Re-use human Urine collected in Ger-Settlements in Darkhan, Mongolia. Bauhaus-Universität Weimar, Weimar, Germany. (Study thesis).

Schmitz, T. A. (2013). Treatment Options for Digested Faecal Sludge in Darkhan, Mongolia. Bauhaus-Universität Weimar, Weimar, Germany. (Study thesis).

Schuster, C. (2011). Description of Waste Management for the City of Darkhan. Bauhaus-Universität Weimar, Weimar, Germany. (Study thesis).

Schuster, C. (2012). Technische Entwicklung und ökonomischer Vergleich angepasster, leitungsungebundener Sanitärsysteme mit integrierter Abfallentsorgung für Jurten-Siedlungen in der Stadt Darkhan, Mongolei. Bauhaus-Universität Weimar, Weimar, Germany. (Master thesis).

Wolter, S. (2014). Entwicklung eines computergestützten Bilanzierungsmodells für Stoff- und Energieströme aus neuartigen Sanitärsystemen. Bauhaus-Universität Weimar, Weimar, Germany. (Master thesis).

H.3 Some basic data on fertilizer and biowaste

The following table has been taken from (Rutland & Polo, 2005) and summarizes the conversion factors of the primary and secondary plant nutrients and their oxides.

Table 28: Conversion factors of plant nutrients

From oxide to elemental					From elemental to oxide				
P_2O_5	x	0.44	=	P	P	x	2.29	=	P_2O_5
K_2O	x	0.83	=	K	K	x	1.20	=	K_2O
CaO	x	0.71	=	Ca	Ca	x	1.44	=	CaO
MgO	x	0.60	=	Mg	Mg	x	1.66	=	MgO
SO_3	x	0.40	=	S	S	x	2.50	=	SO_3
B_2O_3	x	0.31	=	B	B	x	3.22	=	B_2O_3

The following table shows some parameters of constituents of organic raw material, which can be included in the consideration of material-flows of iSaS. The overview of these parameters supports the orientation with this topic.

Table 29: Value added constituents of organic raw material (average values dry solids) according to (Ottow et al., 1997, p. 143)

raw material	loss on ignition [%]	C/N ratio [-]	N [%]	P_20_5 [%]	K_20 [%]	Ca0 [%]	Mg0 [%]
kitchen waste	20-80	12-20	0.6-2.2	0.3-1.5	0.4-1.8	0.5-4.8	0.5-2.1
biowaste (min max values)	30-70	10-25	0.6-2.7	0.4-1.4	0.5-1.6	0.5-5.5	0.5-2
garden and green waste	15-75	20-60	0.3-2	0.1-2.3	0.4-3.4	0.4-12	0.2-1.5
domestic waste	25-50	30-40	0.8-1.1	0.6-0.8	0.5-0.6	4.4-5.6	0.80
human excrements	15-25	6-10	2.00	1.80	0.40	5.40	2.10
wastewater sludge (stabilised)	15-30	15	2.30	1.50	0.50	5.70	1.00
wastewater sludge (raw)	20-70	15	4.50	2.30	0.50	2.70	0.60
manure							
- cattle	20.30	20	0.60	0.40	0.70	0.60	0.20
- horse	25.40	25	0.70	0.30	0.80	0.40	0.20
- sheep	31.80	15-18	0.90	0.30	0.80	0.40	0.20
- pig	18.00	-	0.80	0.90	0.50	0.80	0.30
slurry							
- cattle	10-16	8-13	3.20	1.70	3.90	1.80	0.60
- pig	10-20	5-7	5.70	3.90	3.30	3.70	1.20
- chicken	10-15	-	9.80	8.30	4.80	17.30	1.70
- sheep, goat	20-30	-	-	-	-	-	-
beet leave	70	15	2.30	0.60	4.20	1.60	1.20
straw		100	0.40	2.30	2.10	0.40	0.20
fresh bark	90-93	85-180	0.5-1.0	0.02-0.06	0.03-0.06	0.5-1	0.04-0.1

raw material	loss on ignition [%]	C/N ratio [-]	N [%]	P_2O_5 [%]	K_2O [%]	CaO [%]	MgO [%]
bark mulch	60-85	100-130	0.2-0.6	0.1-0.2	0.3-1.5	0.4-1.3	0.1-0.2
wood chips	65-85	400-500	0.1-0.4	0.10	0.3-0.5	0.5-1	0.1-0.15
leaves	80	20-60	0.2-0.5	-		-	
reed	75.00	20-50	0.40	-	-	-	-
peat	95-99	30-100	0.60	0.10	0.03	0.25	0.10
rumen dung	18-40	20	1.50	1.00	0.50	0.70	0.14
rumen content	8.5-17	15-18	1.40	0.60	0.90	2.00	0.60
grape marc	80.8	50	1.5-2.5	1.0-1.7	3.4-5.3	1.4-2.4	0.21
fruit marc	90-95	35	1.10	0.62	1.57	1.10	0.20
tobacco	85-88	50	2.0-2.4	0.5-6.6	5.1-6.0	5.00	0.45
paper	75	170-800	0.2-1.5	0.2-0.6	0.02-0.1	0.5-1.5	0.1-0.4

H.4 Endnotes

[1] ***Improved sanitation:*** For MDG monitoring, an improved sanitation facility is defined as one that hygienically separates human excreta from human contact: e.g. flush toilet, connection to a piped sewer system, connection to a septic system, flush / pour-flush to a pit latrine, ventilated improved pit (VIP) latrine, composting toilet & some special cases.
Unimproved sanitation: For MDG monitoring the following facilities that are considered as "unimproved": e.g. flush/pour flush to elsewhere, Pit latrine without slab, bucket, hanging toilet or hanging latrine, no facilities or bush or field.
See more information on: www.wssinfo.org/definitions-methods/watsan-categories/

[2] 2015 report on *"Progress on sanitation and drinking water"* (WHO and UNICEF, 2015, p. 12): *"During the MDG period, it is estimated that use of improved sanitation facilities rose from 54 per cent to 68 per cent globally. The global MDG target of 77 per cent has therefore been missed by nine percentage points and almost 700 million people."*

[3] All these concepts and approaches can easily be accessed through the website www.susana.org

[4] The UN has named this figure throughout all MDG reports and other related documents respectively during the last 16 years. It remains unclear, whether this figure has ever been fundamentally revised.

[5] ***Ger area***: "Ger" is the Mongolian word for the traditional tent of the nomads. "Ger area" are areas around developed city centres in Mongolia without basic sanitary infrastructure and water supply respectively.

[6] The ***"Liernur System"*** can be seen as the forerunner of modern vacuum sewer systems. (source: http://en.wikipedia.org/wiki/Vacuum_sewer)

[7] The ***"Heidelberger Tonnensystem***" is a dry sanitation system for the collection of faecal matter. It consisted of collection bins and horse carts as transport mean. The faecal matter was either composted or directly used in agriculture (Mittermaier, 1897).

[8] German original text: So lange es sich aber um die Allgemeinheit der Frage handelt, kann man gewiss darüber nicht im Zweifel sein, dass es höchst unpraktisch ist, Millionen von Werth in Dünger wegzuwerfen und sich auch noch Kosten dazu zu machen, diese Millionen zu vergeuden

[9] ***Peru Guano***: Guano has a high content of the three major plant nutrients (N, P, K) and is a highly effective fertiliser. In the 19th century the trade with guano played an important role. Guano has been one of the main import goods from the colonies to the industrialised countries in Europe at that time. (source: http://en.wikipedia.org/wiki/Guano)

[10] German original text: "Selbst die unbemittelte Classe würde gezwungen sein, zu diesem Wegwerfen beizutragen und statt dessen Peru Guano und andere künstlichen Düngmittel anzukaufen, um einen kleinen Gemüsegarten oder dergleichen unterhalten zu können."

[11] German original text: "Was die städtischen Finanzen betrifft, so befinden sich die Städte mit Abfhur ebenso wohl, wie die canalisirten Städte unter den hohen Kosten schwer leiden, während mit der Abfuhr überall eine im steigendem Aufblühen begriffene Land- und Garten-Cultur der Umgegend Hand in Hand geht, wodurch die Lebensmittel der Stadt wohlfeil werden."

[12] German original text: "Die Durchdringlichkeit der Canalwandungen ist überall zugestanden. Am meisten have ich mich davon bei einer Begehung der eben im Bau begriffenen Canäle zu Frankfurt a.M. überzeugen können, welche ich unter der Leitung des berühmten Fachtechnikers Herrn Lindley und anderer Herren bei Gelegenheit der letzten Naturforscher-Versammlung vornahm. Das Grundwasser drang so reichlich durch das Mauerwerk, dass sich auf der Canalsohle ein kleiner Bach gebildet hatte, auch wo noch gar keine Einleitung auf anderen Wegen erfolgt war. ... Dieser Umstand hat unzweifelhaft etwas Bedenkliches an sich, insofern die Möglichkeit, dass nachher auch von innen nach aussen eine ähnliche Penetration erfolge, nicht ganz ausgeschlossen werden kann u.s.w."

[13] ***Rudolf Carl Virchow*** (13 October 1821 – 5 September 1902) was a German doctor, anthropologist, pathologist, prehistorian, biologist, writer, editor, and politician, known for his advancement of public health. He is known as "the father of modern pathology" because his work helped to discredit humorism, bringing more science to medicine. He is also considered one of the founders of social medicine. As politician he worked to improve the health-care conditions for the Berlin citizens, namely working towards modern water and sewer systems, but has been emphasizing the need to implement adapted sanitation systems based on local conditions. (source: http://en.wikipedia.org/wiki/Rudolf_Virchow)

[14] Mr Lindley refers to ***William Lindley*** (1808-1900) or his son William Herrlein Lindley (1853-1917), both of whom have been English engineers who designed dozens of water and sewage systems across Europe in the 2nd half of the 19th century. They both have worked in Frankfurt in the 1860s, but it was most likely the older Mr Lindley to whom the historical source refers to. Mr Lindley designed modern drainage and sewage systems for the city of Hamburg in the 1840s to 1860s. His engagement in the construction of sewage works in Frankfurt a.M. in 1863ff helped to reduce the death rate of typhoid by a factor of 8. (source: http://en.wikipedia.org/wiki/William_Lindley)

[15] ***Sewage farms*** comprise agricultural land irrigated and fertilised with sewage. They were used in many European countries, North America and Australia for the treatment of wastewater and can be considered as the predecessor of trickling filter and constructed wetlands. With growing wastewater quantities and organic and chemical loads they they were not suitable anymore for the sufficient treatment and also became contaminated and unsuited for agricultural use. However some of them remained active until the end of the 20th century (e.g. in Berlin, Dortmund, Braunschweig Freiburg) (source: http://en.wikipedia.org/wiki/Sewage_farm).

[16] Justus Freiherr ***von Liebig*** (12 May 1803 – 18 April 1873) was a German chemist who made major contributions to agricultural and biological chemistry, and was considered the founder of organic chemistry. He is considered the "father of the fertilizer industry" for his discovery of nitrogen as an essential plant nutrient, and his formulation of the Law of the Minimum, which described the effect of individual nutrients on crops (source: http://en.wikipedia.org/wiki/Justus_von_Liebig).

[17] German original text: „Was die praktische Ausführung anbelangt, so lehrt uns die Erfahrung, dass tiefgreifende Reformen im täglichen Leben selten durch Belehrung und Ueberzeugung, sondern fast immer nur durch die Noth und empfindliche Schicksalsschläge zur Durchführung gelangen. So muss auch das gegenwärtige „Kanalisationsfieber“ erst einmal ausgetobt haben und das nachfolgende Siechthum städtischer Finanzen und die Enttäuschung verfehlter Bauanlagen durchgenossen werden, um den Weg zu rationellen Reformen zu ebnen. Damit der Leser aber aus diesem Ausspruche nicht etwa den Schluss ziehe, dass hiermit der Verfasser mit Sack und Pack in die Sekte der „Abfuhrmänner“ eintrete, so setzt er hier gleich vorgreifend sein ganzes Programm in einzelnen Sätzen hin: 1) Tiefgehende Drainirung des Baugrundes. 2) Oberirdische Ableitung der atmosphärischen Niederschläge. 3) Unterirdische Ableitung von allem öffentlichen und privaten Gebrauchswasser durch ein isolirtes enges Kanalnetz. 4) Abfuhr der unvermischten Excrementalstoffe und deren Zerstörung durch landwirthschaftliche Verwendung. 5) Entfernung aller schädlichen Gase und unangenehmen Gerüche durch rationelle Ventilation der Entstehungsherde“.

[18] German original text: **Duden**: (bildungssprachlich) [Wieder]herstellung einer Einheit [aus Differenziertem]; Vervollständigung (bildungssprachlich) Einbeziehung, Eingliederung in ein größeres Ganzes
(Soziologie) Verbindung einer Vielheit von einzelnen Personen oder Gruppen zu einer gesellschaftlichen und kulturellen Einheit

[19] Accoding to Duden the adverb or adjective “integrated” is defined as: “*so beschaffen, dass Unterschiedliches, Verschiedenartiges miteinander verbunden, vereinigt ist“*

[20] The explanation of the three forms of integration are compiled from online sources: www.wikipedia.org and www.wirtschaftslexikon.de . Other sources of information vary slightly in their definition.

[21] see also: “Entwurf eines Gesetzes zur Umsetzung der UVP-Änderungsrichtlinie, der IVU-Richtlinie und weiterer EG-Richtlinien zum Umweltschutz“, Deutscher Bundestag, Drucksache 14/4599, http://dip21.bundestag.de/dip21/btd/14/045/1404599.pdf

[22] The ***three pillars of sustainability*** have been identified as the 2005 World Summit on Social Development as sustainable development goals: economic development, social development and environmental protection. This view has been expressed as an illustration using three overlapping ellipses indicating that the three pillars of sustainability are not mutually exclusive and can be mutually reinforcing. Often they are also referred to a ***triple bottom line*** in industrial standards (source: https://en.wikipedia.org/wiki/Sustainability).

[23] ***Parameter*** is a kind of variable, which is used to describe the state of a system. It refers to a certain set-up. In a different set-up the value of the parameter can be different. The semantic differentiation between *parameter* and ***variable*** is not exact. In the iSaS model a *parameter* defines the basic input data, whereas the notion *variable* is used, once the input data is assigned in the iSaS model or in case a variable is newly defined in the model itself. The value can be constant or varying.

Curriculum Vitae

Personal Details

Name	Jürgen Stäudel
Date of birth	11 June 1973
Place of birth	Marktredwitz / Germany

Work Experience and Extended CV

Personal Profile on LinkedIn:
https://www.linkedin.com/in/lotconjst/

Engineering Consultants LotusConsulting:
www.lotusconsulting.eu

Education, Publications and Research

Personal Profile on ORCID
orcid.org/0000-0002-8595-6671

My son, beware of anything beyond these.
Of making many books there is no end,
and much study is a weariness of the flesh.

in the Bible, Ecclesiastes Chapter12, Verse 12

„Und darüber hinaus, mein Sohn,
lass dich vor ihnen warnen!
Das viele Büchermachen findet kein Ende.
Und das viele Studieren ermüdet den Leib.“

Die Bibel, Das Buch Prediger, Kapitel 12, Vers 12