Market Potential of a Membrane Based Wastewater Treatment Plant for Decentralized Application in China

An economic evaluation of a potential large-scale product

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Abstract english

China – an interesting market for decentralized wastewater treatment

The largely successful centralized wastewater treatment concept has shown its limits in some developing and transition countries like China, especially in fast-growing cities with limited water resources. Decentralized sanitation with its modular character is considered to be an effective way in facing rapid urban growth and with its potential to locally reuse water an additional water resource can be tapped. A master thesis from the EPFL Lausanne, supervised by the Swiss water research institute Eawag and supported by the marketing institute Chinese Business Center CBC from Shanghai and the investment company Emerald Technology Ventures, investigated the market potential in China for membrane based wastewater systems in decentralized application of urban wastewater treatment. A survey with international system suppliers and Chinese experts form authorities, academics, and real estate developer companies has been conducted to acquire relevant information.

With a wastewater treatment rate of 22% sanitation in China is poor and leads to extensive environmental consequences. The protection of public health and the conservation of water resources as the main goals of a sanitation system are not achieved. Hence, the Chinese Government is initiating large investments in wastewater treatment. Chinese experts admit that the most effective allocation of governmental funds, water scarcity and increasing problems with sludge are main reasons in China considering decentralized wastewater concepts as an alternative to conventional systems.

Many technologies could be considered for decentralized wastewater treatment. To answer the water scarcity and the sludge issue at once membrane technology is seen as a promising technology. Membrane technology with its modularity is applicable for space-saving decentralized use. Different prototypes are available in the market for wastewater treatment of 4 up to 500 residents. The specification in the thesis has been set on 300 residents. Answers from Chinese

experts proof that the membrane based wastewater treatment system could offer 20% economies of scale through large-scale production of more than 1.000 quantities per year. Therefore, an economically interesting effect is created while decentralized concepts are about outrivaling centralized sanitation systems. Applying this wishful product to the reference concept *Swiss sanitation market* a theoretical market share between 12% and 24% could be captured. From a Chinese wastewater market point of view factors like distribution of the new product, operation and maintenance services, and system controls are important besides the economies of the product for successfully rolling out this system.

According to the qualitative analyzes on water scarcity and the quantitative economies of scale calculations two main market segments for this wishful decentralized membrane based wastewater treatment system can be derived. The first market segment are new municipal buildings in the 321 major Chinese water scarce cities with a buying motive of 100% due to the assumption that compulsory regulations for the installation of this system are imposed. According to the cost comparison method evaluation, the annual market potential in this segment for the decentralized wastewater treatment product would exceed 12.000 million Chinese Yuan @ PPP. Second, with a pure economic consideration and without any political regulations, the buying motive of the first market segment would still be 2 to 8% leading to an annual market potential of 244 to 977 million Chinese Yuan @ PPP. The market for services as operation and maintenance could additionally reach 139 to 554 million Yuan @ PPP per year for the latter market segment.

A small problem in China multiplied by 1.3 billion people can turn into a very large problem, while a small solution multiplied by 1.3 billion people can make a very large change. Wastewater currently causes a large problem in China. Thus, solutions like decentralized wastewater treatment with membrane technology could help starting this large change.

Abstract german

China – ein interessanter Markt für dezentrale Kleinkläranlagen

Die konventionelle, zentrale Abwasserreinigung ist ein weltweit erfolgreiches Konzept, das in Entwicklungs- und Transformationsländern wie China und insbesondere in wasserarmen Städten mit rasendem Bevölkerungswachstum an seine Grenzen stößt. Der modulare Charakter von dezentralen Abwassersystemen gilt als eine effektive Möglichkeit der schnellen Städteentwicklung nachhaltig zu begegnen. Gleichzeitig könnte das gereinigte Abwasser lokal wieder verwendet werden als zusätzliche Wasserressource. Eine Masterarbeit der EPFL Lausanne, betreut durch das Wasserforschungsinstitut Eawag, sowie unterstützt vom Marktforschungsinstitut Chinese Business Center CBC in Shanghai und der Emerald Technology Ventures, erforschte das Marktpotential in China für Kleinkläranlagen mit Membrantechnologie zur Reinigung von städtischem Abwasser. Dazu wurde eine Umfrage bei internationalen Systemanbietern, Chinesischen Behörden, Akademikern und Generalunternehmungen durchgeführt.

Mit 22% ist die Abwasserreinigungsrate in China sehr tief, was phänomenale Konsequenzen für die Umwelt zur Folge hat. Die Siedlungshygiene und der Schutz von öffentlichen Gewässern als die Kernziele eines Abwassersystems werden nicht erfüllt. Aufgrund dessen plant die Chinesische Regierung hohe Investitionen in der Abwasserreinigung. Dezentrale Systeme werden in China als wertvolle Alternativen zu konventionellen Abwasserkonzepten gesehen, um eine möglichst effektive Allokation der Investitionsgelder zu erreichen und gleichzeitig der Wasserknappheit und dem wachsenden Klärschlammproblem zu begegnen.

Diverse Technologien könnten in der dezentralen Abwasserreinigung eingesetzt werden. Um den Fragen der Wasserknappheit und des Klärschlammproblems gleichzeitig zu begegnen, wird die Membrantechnologie als viel versprechend begutachtet. Die modulare Membrantechnologie kann in dezentralen Systemen Platz sparend eingesetzt werden.

Verschiedene Prototypen sind bereits im Abwassermarkt bereits erhältlich für eine Anwendung von 4 bis 500 Personen. In der Studie wurde eine membranbasierte Kleinkläranlage für die dezentrale Anwendung von 300 Personen spezifiziert. Die Chinesischen Experten geben an, dass durch Massenproduktion dieser Anlage in China rund 20% Skalenerträge bewirkt werden könnten ab einer jährlichen Stückzahl über 1.000. Somit könnten dezentrale Anlagen konventionelle Abwassersysteme auch ökonomisch übertreffen. Neben wirtschaftlichen Faktoren sind Vertrieb und Installation der Kleinkläranlage, Unterhaltsleistungen und Kontrollfunktionalitäten wichtige Faktoren für eine erfolgreiche Lancierung in China.

Anhand qualitativer Analysen um die akute Wasserknappheit und quantitativer Skalenertragsberechnungen können zwei Marktsegmente für die erwünschte membranbasierte Kleinkläranlage hergeleitet werden. Als erstes Marktsegment gelten neue Wohneinheiten in den größten 321 Chinesischen Städten mit einem Kaufmotiv von 100% aufgrund der Annahme, dass die Installation der Kleinkläranlage als obligatorisch definiert wird. Nach der Kostenvergleichsmethode erarbeitet, übersteigt das jährliche Marktpotential für das Produkt 12.000 Millionen Chinesische Yuan @ PPP. Aus reiner ökonomischer Betrachtungsweise ohne politische Regulierungen würde das Kaufmotiv noch immer bei 2 bis 9% liegen, was zu einem beachtlichen jährlichen Marktpotential von 244 bis 977 Millionen Chinesische Yuan @ PPP führen könnte. Für Systemanbieter, die neben dem eigentlichen Produkt operative Unterhaltsleistungen und Kontrollaufgaben übernehmen können, öffnet sich ein Markt zwischen 139 bis 554 Millionen Yuan @ PPP pro Jahr.

Ein kleines Problem in China multipliziert mit 1.3 Milliarden Menschen wird zu einem sehr großen Problem, währenddem eine smarte Lösung multipliziert mit 1.3 Milliarden Menschen eine große Veränderung bewirken kann. Abwasser verursacht ein Riesenproblem in China. Daher könnten Lösungen wie die membranbasierte Kleinkläranlage eine Veränderung initiieren.

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Glossary

bn	billion
BOT	build-operate-transfer
CHF	Swiss Franc
CNY	Chinese Yuan
CMD	cubic meter per day [m^3 d^{-1}]
COD	chemical oxygen demand
DS	dry substance
FYP	five year plan
LCC	life cycle costing
m	million
MBR	membrane bioreactor
MF	microfiltration
NH_4^+	Ammonium
O&M	operation and maintenance
PPP	purchasing power parity
TEDE	short word for 'technological desire' standing for an on-site membrane based wastewater treatment plant
UF	ultrafiltration
WWTP	wastewater treatment plant

Note: In April 2007 the official currency exchange rate CHF to CNY was 6.348 CNY/CHF (CHINA KNOWLEDGE, 2007).

1 Introduction

A small problem in China multiplied by 1.3 billion people can turn into a very large problem, while a small solution multiplied by 1.3 billion people can make a very large change. Wastewater currently causes a large problem in China. Solutions to make a large change are urgently needed. This master thesis report is a small attempt contributing to that huge challenge. The Swiss Federal Institute of Aquatic Science and Technology Eawag is internationally well known for its research studies in *Water Resources Management*. To accomplish the *Water Resources Management* Master of Advanced Studies at the Swiss Federal Institute of Technology EPFL a thesis together with Eawag has been chosen to investigate on urban wastewater in China. Additionally, the study has been supported by the investment company Emerald Technology Ventures and the marketing research institute CBC China Business Center in China. This first introducing chapter defines the research questions, gives an overview over the report's content and as well shows its limitations.

1.1 Background, objective and content

The World Bank (WB ONLINE, 2007) defines water resources management as an integrating concept of water sub-sectors such as sanitation, which ensures that social, economic, environmental and technical dimensions are taken into account. The thesis report is attending to all of these dimensions. The core of this study is to find out more about market potential in China for membrane based wastewater systems in decentralized application of urban wastewater treatment. Thereby, drivers for decentralized infrastructure in China, the hype of the membrane technology, as well as the cost and investment side of the wastewater business have been assessed. As a reference concept the Swiss sanitation system has been chosen to classify Chinese information and data. Expert interviews with international system suppliers, Chinese governmental organisations, Chinese and Swiss academics, and Chinese real estate developer companies have been conducted to acquire relevant information. In the following two sub-chapter research questions standing behind the reports' goal are described and the content of the report is given.

1.1.1 Research questions

Defining and calculating a market potential for membrane based decentralized wastewater treatment in China as the objective of the thesis comes along with answering four questions of economic, social, environmental and technical character:

- *Question 1:* What are limitations of conventional wastewater treatment and what are the drivers for choosing decentralized sanitation concepts in China? (see chapter 3)
- *Question 2:* Can membrane technology support the Chinese choice for decentralized sanitation and what is the performance of membrane based wastewater treatment applications? (see chapter 4)
- *Question 3:* If the membrane based wastewater treatment application for decentralized use causes an investment challenge, can it be faced by large-scale production? (see chapter 4)
- *Question 4:* Where and under what circumstances is a market for decentralized membrane based wastewater treatment defined? (see chapter 5)

1.1.2 Content of the report

The report consists of six main chapters. The introductory chapter is followed by chapter 2 where the theoretical background and methods of this study are presented. Chapter 3 describes the characteristics of conventional centralized and prosperous decentralized wastewater treatment. The focus is set on factors like water scarcity that can have an influencing role for a paradigm change towards decentralized wastewater concepts. Chapter 4 presents the promising membrane technology in application for decentralized use. As new technologies generally have the disadvantage to be too expensive in the market, potential cost decrease by large-scale production of the membrane based application is illustrated as well. Chapter 5 aims at providing qualitative and quantitative market information for membrane based wastewater treatment systems. A conclusion of the reports' analyzes are presented in chapter 6.

1.2 Limitations

The subject of the study is highly complex regarding the broad and very inhomogeneous water and wastewater aspects of China. Thus, some limitations are made. The first limitation is of geographical nature. Most facts and data originate from the three economical well developed areas Shanghai, Beijing and Tianjin, with the effect of potentially underestimating the wastewater market state and complexity from little developed regions.

The term water resources management is broadly diversified. The focus of this study is set on urban sanitation, water reclamation and drinking water supply concepts are discussed marginally. For reasons of not getting lost in the depth of technological wastewater applications the choice for only one technology – the membrane technology - has been made. An involuntary renouncement is caused in not finding profound and reliable wastewater market data from China. To approach this gap data from Swiss sanitation system has been fetched for further data comparability.

Wastewater management in general is a close interaction of stakeholders from government, business, associations and real estate developer. Understanding this stakeholder system and especially the organisational structure of China with its interdependencies is complex and has not been further analyzed during this thesis. A next complexity forms the characteristics of the Chinese water law and its regulations. Political and legislative effects have been included as much as necessary.

1.3 Acknowledgement

A Chinese poem says: *One fails to see the genuine appearance of the Mount LU, just for his staying within the mountains*. With regard to this poem I would like to express my gratitude's to over 100 persons I had the pleasure to rely on for this study. First of all, there were many persons helping me building up mountains of data and information for this study. Thus, thanks goes to professionals from the Eawag research institute, to specialists from the Swiss water business, and mainly to Chinese experts from academics, authorities, from real estate and system suppliers. A special thank to Frank CHEN from Geberit for connecting me to high rank experts in China. Finding the path through Chinese mountains of inspiration and information during the survey has been made very convenient by the CBC China Business Center team in Shanghai and Beijing, namely I thank a lot to Charles MERKLE, Andreas KRIESI, Helen ZHU, Diana ZHU and Janet GONG. Not to forget stepping back from time to time and considering Mount LU from an eagle's perspective was due to Matthias BLUNSCHI and my friends. Most thanks to Bernhard TRUFFER for giving me an excellent help in shovelling away mountains of information in regard to address to the genuine of this study.

2 Theoretical background and methods

A qualitative survey by means of personally examined interviews with various Swiss, German and Chinese experts as well as a comprehensive primary desk research in literature were the two main data sources in order to collect and assess information about wastewater treatment, membrane technology and market information about China. The definition of the market potential is an integrative part of a business plan. Thus, the questionnaire of the survey and this report have been structured in the logic of a business plan. The first sub-chapter describes the key elements of a business plan and how a market potential is evaluated. Then, as market potential is quantified, the second sub-chapter attends to the definition on full cost calculations. Third, survey technique and the selection of the experts are described.

2.1 Business plan, market potential and segmentation

According to McKinsey (2000) a business plan is an essential framework for corporate planning and communication tool to convince key shareholders. The *company & organisation*, *product idea*, the *market & competition*, *strategy & realisation* plan, and the *finances* can be named as the five cornerstones ob a business plan. The element *market & competition* includes market segmentation and market potential estimations. This fact makes the business plan concept interesting for the study. Therefore, the first three business plan cornerstone elements have been abstracted: The *Company* is assumed to be wastewater treatment as a whole. The membrane based wastewater treatment plant is supposed being the new *product idea*. The Chinese wastewater market includes the market potential estimation and is therefore assumed to be the *market* for the new product idea. *Strategy* and *finances* have not been discussed and would be subject to a company intending to penetrate the Chinese market with such a product in reality.

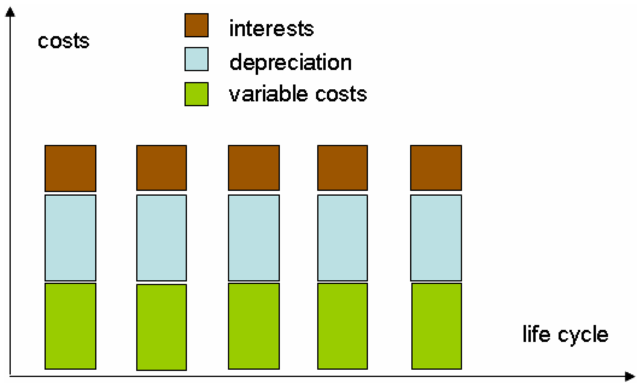
In marketing, the term market refers to the group of consumers or organizations that is interested in the product, has the resources to purchase the product, and is permitted by law or other regulations to acquire the product (NET MBA, 2007). The market definition begins with the population respectively the mass of consumers of a product as the largest layer for selling a product. The next smaller layer of a market is the market potential with its share of the total population who has interest in acquiring the product under optimal conditions. Since the market is likely to be composed of consumers whose needs differ, market segmentation is useful in order to better understand those needs and to select the groups within the market that a company will serve (NET MBA, 2007). Markets can be segmented on the costumers characteristics *geographic, demographic, and behavioralistic* and for segments to be practical they should be measurable. The treatment of one part of the market as a homogenous group is called mass marketing, offering the same product to all customers. Mass marketing allows economies of scale to be realized through large-scale production and mass distribution. The drawback of mass marketing is that needs and preferences differ and the same offering is unlikely to be viewed as optimal by all customers.

2.2 Investment comparison method

The market analysis of this study contains quantitative data like investment and operation costs. As investment costs play a critical role in decision-making the determination and comparison of current and future costs require a proper definition of the cost elements. For comparison purposes currencies are converted to Swiss Francs with the official exchange rate *1CHF = 6.348 CNY*. Purchasing power parities PPP *1CHF = 0.947 CNY* effects are given to illustrate the costs as experienced by Chinese purchase power (for details see *Annex 1*).

Investment data found from the Swiss and Chinese wastewater business often were total investment costs without giving any information about interests or other important information like depreciation rates or about the treatment quality. A business-management method therefore was required to compare fixed and variable cost elements of centralized and decentralized wastewater concepts. The classical *cost comparison method* has been chosen as this static investment evaluation method serves in comparing investment alternatives (THOMMEN, 1996). The cost comparison method considers average costs of a period respectively of one year. Thus, the fixed investment costs have to be converted into annual capital charges containing depreciation and interests (see *Figure 1*). For this study, variable costs comprehend annual recurring operation as well as maintenance costs including minor re-investments.

Figure 1: Scheme of the classic cost comparison method



2.3 Survey and stakeholder selection

Knowing the views of decision makers and industry experts provides invaluable strategic information in general. For this study having a broad spectrum of strategic information and coherences is much more relevant that building up representative information. Hence, the technique of an explorative expert survey has been chosen, whereby the expert interviews were hold in an open one- to two-hour discussions using a semi-structured and -standardized questionnaire (see *Annex 2*). The interviews were structured in three parts: In *Part I*, the Chinese centralized sanitation system was discussed and the decentralized concept was evaluated. In *Part II*, membrane technology in China was assessed and its decentralized application discussed. In *Part III* experts could give their appraisal where and under what circumstances decentralized applications could be introduced in the Chinese wastewater market. Technical fact sheets (see *Figure 2*, *Figure 7*, and *Figure 11*) were prepared to help conveying information to experts during the interviews (MEDILANSKI, 2006). Voice recording was not appreciated by the interviewed experts and therefore no digital record is available. In order to evaluate the qualitative statements of the survey the answers were written down during the interviews. As the interviews usually took place in Chinese, the answers were translated first and then written down.

An expert is defined as a person with a specific responsibility for the draft, implementation and control of a problem solution, as well as having privileged access to information (MEUSER, 1991). For the study four groups were formed out of experts who would play an important role in introducing decentralized membrane based wastewater treatment plants in China: Systems suppliers, authorities, real estate developer, and academic. Representative of those groups 22 Chinese stakeholders have been selected and interviewed. In advance, 17 Swiss and German specialists in the fields of wastewater treatment, membrane technology, China and water, China and real estate, large-scale production, and water investments have been interviewed to build up background information, as well as to prepare and test the questionnaire, and to access *the right experts.* The list of Chinese experts and Swiss specialists can be found in *Annex 3*.

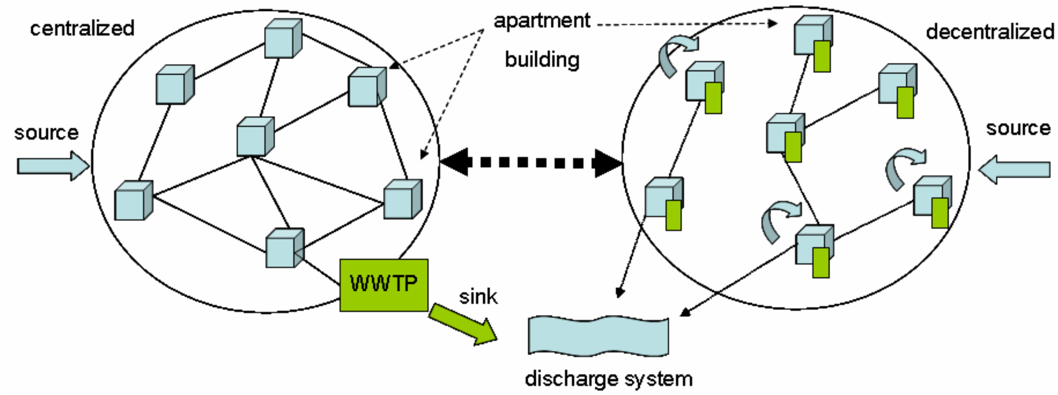
3 Centralized and decentralized sanitation in China

Centralized municipal and industrial sanitation in industrialized countries epitomizes a successful concept of protecting water resources and guaranteeing urban hygiene and comfort. One reason the concept is now being challenged are the increasing investment requirements to connect remote areas and to replace aged sewer systems. Another reason is the difficulties of exporting the concept to water-scarce countries experiencing rapid urban growth (LARSEN, 1997).

Decentralized sanitation with its modular and flexible character is considered to be an effective way in facing rapid urban growth and with its potential to locally reuse water an additional water resource could be tapped on-site. At life cycle costs comparisons decentralized sanitation could be to some extent even more economic than centralized sanitation. Beside an extensive social and economical transformation process in industrialized countries a switch from centralized to decentralized sanitation would lead to large sunk costs combined with a large investment peak for the new system. From an economic perspective this seems to be an almost unthinkable situation – to be called *deadlock* situation. Thus, no real market for decentralized wastewater concepts opens up in industrialized countries.

Countries like China hardly having any wastewater treatment in place or experiencing rapid urban construction development are not struggling with a deadlock situation. Currently, with increasing environmental pressure China needs and wants to invest in urban municipal wastewater treatment. Thus, the main question of this study is, where and under what circumstances decentralized wastewater treatment has market potential in China. Analyzing the drivers for decentralized sanitation in Chinese urban areas first requires understanding and comparing centralized and decentralized sanitation regarding current state, function and costs in general and for China. The Swiss sanitation system hereby gives the reference concept.

Figure 2: Fact Sheet I – schematized centralized and decentralized wastewater concepts



3.1 Centralized sanitation

This chapter describes the goals, current state, function and costs of centralized municipal sanitation in general respectively for Switzerland and for China in order to outline the benchmark for decentralized concepts discussed in sub-chapter 3.2.

3.1.1 Definition in general

The main objectives of a wastewater system – protection of public health by enhancement of urban hygiene and comfort, protection and conservation of water resources, and rainwater discharge - can be guaranteed with centralized sanitation concepts. In industrialized countries mainly conventional centralized systems in different layouts have been set up the past decades as the key system requirements – political stability, financial solvency and sufficient water availability – have been given.

In such systems any type of wastewater is collected on-site by an in-house piping system and drained to the sewerage. The sewage, diluted by rainwater, is conducted through the sewerage towards a lower and remote based central treatment unit including sludge treatment. Industrial wastewater rather often is treated or partially treated in these central treatment units too. Sanitation consists of three main components: connecting pipes from household to the central sewer system, the sewer system itself and the treatment facility. The investments of the latter two elements are funded by the government. House owners themselves have to invest for the connecting pipes.

An exemplary capacity of a large Swiss wastewater treatment plant constructed for 50.000 residents of a medium size city. A treatment plant for a village with 500 residents still is considered as a central treatment facility (MAURER, 2006, adapted). As almost all cities and villages have their own sanitation system the treatment rate of Switzerland is around 95%. It is estimated, that around 5% of the sewer pipes are leaking.

Centralized wastewater concepts in industrialized countries have proven its advantages. Treatment technology has become sophisticated at predictable investment and maintenance costs and enjoys public acceptance. But for reasons of sustainability, increasing investment requirements, and the often missing transparency in managing the invested public capitals, the concept is now being challenged (LARSEN, 1997). In order to underline these challenges more advantages and disadvantages are listed in *Figure 3*:

Figure 3: Advantages and disadvantages of centralized wastewater systems (ZAIDI, 2005, adapted)

	Advantages	Disadvantages
Technical	+ Familiar and developed technology + High performance according to up-to-date standards	- Inadequate treatment capacity: underutilization when no rain, limitations when a lot of rain - Oversized system: drinking water used for flushing - Leaking sewer system - Little flexibility

	Advantages	Disadvantages
Economic	+ Predictable investment and O&M costs	- Financing peeks for construction works (hard ware) - Initial subsidising by government, re-investments not ensured in a long-term perspective

	Advantages	Disadvantages
Social / environmental	+ Protection of water resources + Control and safe-guarding hygienic security + Protection of infrastructure due to reduction of flooding + Public acceptance + Good control over a single centralized facility + Comfort in utilization – easy O&M management by a community	- Low treatment efficiency low (WB, 2001) - High consumption of water as transport medium, thus system not adequate for regions with water scarcity - Dependency on centralized services can lead to high vulnerability - Dilution of nutrients - Risks of contamination (leaking sewerage)

3.1.2 Definition and status quo of Chinese sanitation

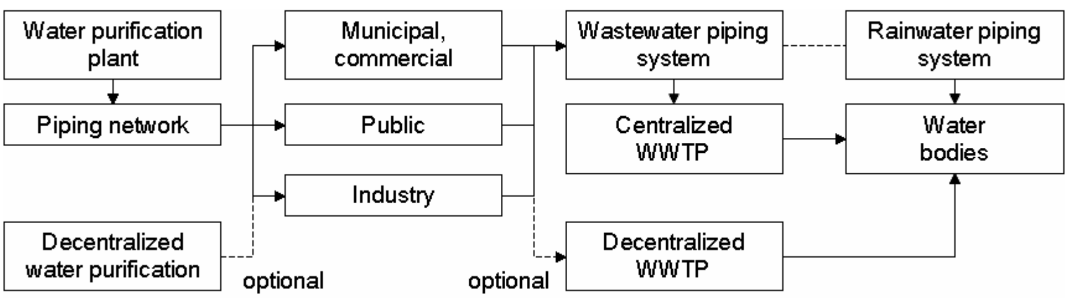
First a definition of residential areas is given in order to understand the scale of Chinese sanitation. China is divided into 3 administrative layers (simplified, for details see MI, 2001): *provinces, districts and communities* with different political status. The layer *provinces* counts 23 provinces, 4 municipalities, 5 autonomous regions, and 2 special administrative regions (for details see *Annex 4*). The layer *districts* includes 664 cities and many smaller districts that are split up in thousands of villages and communities. This study focuses on these 664 major cities plus the 4 municipalities (XU, 2006) making up the *urban population of China* where among 43% of the Chinese population is living (NBS I, 2006). The number of these cities is growing due to rapid urbanization. A village becomes a major city when its population exceeds 60.000 residents, respectively if the average build-up area is 17 km^2 (MI, 2001). To illustrate the extent of the 668 cities see the following list:

- 14 extra-large cities with population over 4 million / build-up area 150 km^2
- 27 extra-large cities with population between 2 and 4 million / build-up area <150 km^2
- 138 large cities with population between 1 and 2 million / build-up area 62 km^2
- 279 large cities with population between 500.000 and 1 million / build-up area <62 km^2
- 171 medium-sized cities with population between 200.000 and 500.000 / 33 km^2
- 39 small cities with population between 60.000 and 200.000 / build-up area >17 km^2

Chinese water supply is centrally organized with an almost complete grid providing tab water for domestic and industrial use to the major cites (NBS I, 2006). Unlike to small towns and villages in rural areas where the drinking water is direct used from raw water sources without any purification. For specific utilization such as tourist resorts or industry plants with high quality water demand tab water is purified with decentralized point of use applications.

Sanitation in China has not yet an area-wide extent as in industrialized countries. Especially in small towns and villages sanitation is very poor. For nearly all major cities sewage disposal is organized in different fashions even though the treatment of discharged amounts is still humble. In most rural areas a sewage disposal system is not existent (XU, 2006). Cities rainwater either simply runs off the surface or discharges through conventional sewerage or through separately built rainwater channels. A largely valid system structure for China is shown in *Figure 4*.

Figure 4: Main water supply and sewage disposal concept in Chinese cities (XU, 2006, adapted)



Currently available sewer networks and municipal wastewater treatment plants are centrally organized and state-owned property, although operation rights may be transferred to some enterprises through special authority by government (U.S. DEPARTMENT of COMMERCE, 2005). As population density in cities is very high the three main components mentioned in chapter 3.1.1 reduce to two elements: sewage system and treatment facilities. Thus, hardly any funding from house owners for connecting pipes. Industrial wastewater treatment facilities are often owned by the enterprises or the industry plant owner and operated independently from municipal wastewater.

Data from the Chinese Ministry of Construction indicates that, among Chinas 668 major cities, around 278 cities do not have sewage treatment plants (RESEARCH and MARKET, 2007). The official urban sewage treatment rate 2005 reaches 45% in China (PEOPLE'S DAILY, 2007). However, Chinese experts confirm a more realistic treatment rate of around 22%, because treatment plants often operate below design standard or capacity (for details see *Annex 5* and U.S. DEPARTMENT of COMMERCE, 2005). Up to 80% of the wastewater is therefore let into water bodies without sufficient treatment which leads to phenomenal contamination and annual environmental damage of over 200 billion Chinese Yuan. By definition, a small wastewater treatment unit including secondary treatment technologies is treating sewage of more than 3.000 residents. A large unit treats sewage of 600.000 residents. The construction of pipelines for sewage collection is often delayed due to funding shortages, and due to leaking sewerage the recently built treatment capacity cannot be fully used (expert from group D, *Annex 3*). Most of China's large and medium-sized municipal water plants use domestically produced equipment, whereof malfunctions have been mentioned by the experts. Additionally, sludge accumulation becomes an increasing issue as hardly any sludge is not stabilized nor properly disposed (expert from group A, *Annex 3*).

3.1.3 Costs, pricing and investment plans

This chapter describes the cost elements of centralized sanitation in Switzerland and China, wastewater pricing and wastewater investment plans in China. The three main sanitation components in Switzerland are connecting pipes from household to the central sewer system, the sewer system itself and the treatment facility. Depending on design standards and capacity replacement value without interest of a Swiss treatment unit is between 600 and 1.500 CHF/capita (MAURER, 2006). Economies of scale through the installation of large treatment units instead of small ones are remarkable looking at the replacement costs difference of small and large treatment units. The average depreciation rate of a centralized wastewater treatment plant is indicated to be 33 years thus, the replacement value is between 18 and 45 CHF/capita/year.

Getting similar data from China is rather difficult. Treatment plants are hardly comparable to Swiss treatment plants due to large difference in size and especially due to different treatment technologies applied. Currently, cost consuming sludge treatment technologies are hardly installed in China (expert from group B, *Annex 3*). As a benchmark several experts indicate investment costs to be between 1.800 and 2.200 CNY/capita (equals to 284 to 347 CHF/capita; expert form group D, *Annex 3*). The depreciation rate in China is indicated to be not more than 25 years thus, the replacement value is assumed to be between 11 and 14 CHF/capita/year (calculation see *Figure 5*). In China, the scale of a small treatment plants is already high that similar economies of scale as for Swiss systems is hardly possible.

Figure 5: Cost comparison of centralized wastewater treatment between Switzerland and China

	Swiss			China		
	low cost	high cost	unit	low cost	high cost	unit
Replacement value WWTP	600	1500	[CHF/capita]	1800	2200	[CNY/capita]
Depreciation	33	33	years	25	25	years
Replacement WWTP per year	18	45	[CHF/capita/year]	72	88	[CNY/capita]
Share treatment plant	28%	28%		50%	50%	
Share sewer system	72%	72%		50%	50%	
Replacement sanitation system	66	165	[CHF/capita/year]	144	176	[CNY/capita/year]
Replacement sanitation system				23	28	[CHF/capita/year]
Share of Swiss system				**34%**	**17%**	

Comparing costs for sewer system becomes even more challenging as a sewer system is often subsidised by the government and business-management figures are hardly available. It is known from Switzerland that with 72% of overall sanitation costs the lion's share is from the sewer systems (data from MAURER, 2006, adapted). Chinese experts admit that the cost split between treatment plants and sewer system is 50:50 as the population density is much higher than in Europe (expert from group D, *Annex 3*). As shown in *Figure 5*, the extrapolation of the Swiss and Chinese treatment unit replacement values shows that the Chinese sanitation system costs between 17% and 34% of the Swiss sanitation system due to different technology standards applied and shorter sewer systems. Be aware of the fact that these figures exclude interests and operation & maintenance costs. Due to many cost components not considered in the calculation of *Figure 5* for both countries Switzerland and China, these effective figures are not considered for further calculations. Thus, the relation of the data seems more reliable. For further calculations this relation of 17% to 34% is applied.

Past investments in Chinese wastewater system have been mainly funded by the government. To illustrate the return on investment side Chinese water pricing pattern is given. Water and wastewater in China is nowadays priced in regards to scarcity, type of use (agricultural, industrial, municipal, special use such as car washing) and a region's ability to pay. Fees for municipal wastewater vary around 1.0 CNY/m^3 and prices typically rise as one move from South to North of China (HENRY, 2004). According to Chinese experts total wastewater fees cover the treatment plants' maintenance and operation costs. Experts admit that depreciation of treatment and sewer system assets, interests and any other strategic water and wastewater investment costs are not included in the fees. To fully cover costs experts suggest the fees to be at least 2 to 3 times higher.

To make up the huge gap in wastewater treatment as outlined in chapter 3.1.2 investments in treating wastewater of over 90.000 million CNY (14.178 million CHF) are planned during the 11th FYP in order to achieve an overall urban sewage treatment rate of over 60% by 2010 (see *Figure 6*). In order to achieve this ambitious target National Government allocated treatment targets to each province (for details see *Annex 5*). Thus, the demand in each province for additional treatment facilities is expected to skyrocket. Investment focus is set on building up new wastewater treatment plants and as sludge is neither stabilized nor safely disposed over 40% of planned investments will be transferred into the sludge business. Chinese experts underline that appropriate technologies for sludge treatment are largely needed (expert from group B, *Annex 3*). Surprisingly, strategic investments for sewerage are not foreseen in the environmental investment plan of plan of the 11th FYP.

Time for effectuating the investments within five years is very short and effective allocation of the funds will be a challenge for the provinces. Above all, the National Government imposes additional challenges: To date, the benchmark for a wastewater treatment plant in China is between 1.800 and 2.200 CNY/capita as described above. This benchmark needs to be heavily undercut because planned investments provide only 189 CNY/capita (see *Figure 6*). Thus, the pressure for effective allocation of funds is increasingly high.

Figure 6: Investments in 11th FYP

	Treatment capacity	Treatment capacity for	Investment amount	Investment per capita
	[m CMD]	[m people]	[m CNY]	[CNY/capita]
WWTP upgrade	20	118	11'100	94
WWTP new	30	176	33'300	189
Sludge treatment & disposal	30	176	38'800	220
Effluent reuse	6.8	40	9'500	238
Total investments			92'700	

3.1.4 Key statement on centralized sanitation

Conventional centralized wastewater systems fulfil the main sanitation goals successfully. Due to this convenient success industrialized countries like Switzerland approach the disadvantages of centralized sanitation more theoretically than proactively seizing the chance for escaping the deadlock situation. China lacking of an area-wide sanitation system and thus not suffering a deadlock situation is challenging the advantages and disadvantages more objectively. There is a tremendous need for effective allocation of funds into wastewater and sludge treatment.

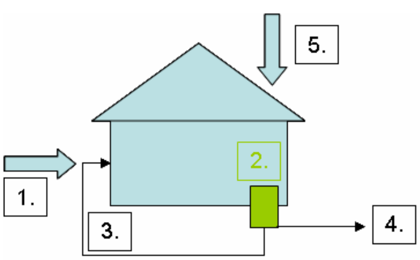
3.2 Decentralized sanitation

Chinese experts mentioned optimized investment allocation for maximal treatment capacity within a limited time frame, solutions for sufficient water availability and answers to the increasing sludge issue as the three main arguments for examining decentralized wastewater concepts as an alternative to conventional systems. Approaching market potential calculation of decentralized wastewater treatment applications as the main goal of the study it is important to first understand decentralized sanitation regarding function, advantages and disadvantages in general and especially in China. The next question is to know Chinese perception on decentralized concepts. Finally, this chapter assesses the question on what extent qualitative and quantitative availability of water is driver for alternative concepts. Analysis on technology, costs and potential for large-scale production of decentralized systems is postponed to chapter 4.

3.2.1 Definition and status quo in general

Many different technologies allow applying a decentralized system for very few residents up to a couple of hundreds. In Switzerland, treatment plants for less than 500 residents are considered as decentralized systems (MAURER, 2006, adapted). Depending on treatment quality and local regulations the effluent is either reused for flushing, let into water bodies, used for groundwater recharge or simply discharged by a simple pipe joining the centralized sewerage. *Figure 7* schematizes the processes of a decentralized sanitation system. To protect the infrastructure from undercutting or other destructions, rainwater is either collected on-site or drained off into water bodies or as well through a simple piping system towards the central sewerage. Besides a numerous research projects on decentralized urban infrastructure systems, practical examples mainly in very specific applications such as industry plants, remote areas and tourist resorts have been tested in industrialized countries.

Figure 7: Fact Sheet II - Decentralized wastewater treatment unit with reuse functionality (XU, 2006)



Initial water supply of 127 [L / (P*d)]

1. Central water supply for drinking, cooking, bathing and washing of 64 [L / (P*d)]
2. On-site MBR treatment of 127 [L / (P*d)]
3. Re-use of treated water flushing and irrigation of 63 [L / (P*d)]
4. Solids and water export of 64 [L / (P*d)] through simple pipe
5. Rainwater discharge through simple pipe

Main advantages of decentralized concepts are its modularity and water reuse potential. Preferably, decentralized concepts are installed if time for environmental change is restricted. With the little dilution of nutrients decentralized systems are considered as sustainable solutions in sanitation. An indirect but strong advantage is potential savings in not building up sewer systems. *Figure 8* summarizes the advantages and disadvantages of decentralized systems. The disaggregated nature of decentralized systems presents a challenge for the operator because many different parties are involved in their use and operation: homeowners, neighbours, installers, managers, inspectors, and regulators all play a role. Where systems are not properly managed, they have a higher failure rate (FANE, 2004). It is therefore a success factor, to provide services, regular inspections, costing and reliability tools to users in order to support in operation and maintenance of wastewater systems (ETNIER, 2005). Like the systems themselves, ownership of the systems is generally dispersed. It is usual that no single organization coordinates investment decisions for decentralized wastewater infrastructure, though local regulators and policy makers may use financial incentives, regulations and penalties to encourage system owners to manage their systems in specific ways (FANE, 2004).

Figure 8: Advantages and disadvantages of decentralized wastewater systems (ZAIDI, 2005, adapted)

	Advantages	Disadvantages
Technical	+ Short and simple sewer systems + Applicable at any scale + Modularity, flexibility + Resource efficient treatment capacity + Little consequence of individual technical failures	- Unfamiliar technology - Performance of prototype applications not yet high enough

	Advantages	Disadvantages
Economic	+ Low costs for sewer system + Robust and reliable technologies that are low in cost (construction, less hardware) + Economies of scale through large-scale production possible + Balanced investment peaks + Life-cycle-costs easy predictable	- New initial financing models required - Operation & maintenance costs often underestimated - Costs for training of professionals

	Advantages	Disadvantages
Social / environmental	+ Quickly installed infrastructure + Source control + Small water consumption for transport + Sludge minimization possible + Treated water as additional water re-source for water scarce area + Maximum recovery and reuse of water and other by-products + Little risk of contamination + Little dilution of nutrients and separation of materials possible + Less land use + Individual responsibility increased	- Control over multiple facilities - Dispersed ownership and operational responsibility - Much installation and operation & maintenance know how required (collective knowledge) - Public acceptance - Hygienic risks in case of O&M and control failures

3.2.2 Definition and status quo in China

Decentralized wastewater treatment has the potential to provide sanitation that meets criteria for sustainable urban water management in a manner that is less resource intensive and more cost effective than centralized approaches (FANE, 2004). Chinese experts have commented both the advantages and disadvantages of decentralized wastewater concept. This sub-chapter defines decentralized sanitation in China and summarizes the expert's opinion on this alternative to conventional wastewater treatment.

China operates in any issue with different scales. Most Chinese experts judge a settlement area of 10 to 20.000 residents as a decentralized unit. Cities in China grow typically following a so-called *satellite pattern* where new settlement areas affiliate to the existing infrastructure. Such a compound counts around 50 high-rise buildings with around 300 persons per building (20 floors multiplied by 5 flats per floor multiplied by 3 persons per flat). Of course, the varieties of settlement patterns are uncountable, but experts define the size as reasonable for further calculations. Some international system supplier represent the opinion to install only one treatment facility for the whole decentralized area, other system supplier vote for installing a treatment unit per high-rise building. For this research study the definition for a decentralized treatment unit sticks for a single high-rise building of 300 residents.

The decentralized concept is not new for China. Most experts knew examples of decentralized applications ranging from on-site pre-treatment in office buildings in the city center of Shanghai to grey-and black water separation in North China including on-site collection of black water up to concrete implementation plans of exactly the concept proposed above (expert from group A, *Annex 3*). All experts opine a very affirmatory position for the decentralized concept for reasons of its flexibility, and accord strongly increasing market potential if the technology applied is reliable. With the recently compulsory imposed regulation in Beijing to provide decentralized treatment and water recycling systems for new residential areas politics give positive signs for decentralized wastewater treatment. Mainly water scarcity can be seen as driving force for such new regulations according to expert's statements. For sensitive areas like the West Lake in HangZhou or other nature resorts of national interest environmental reasons take over a strong driving force for decentralized applications as experts admit that implementing decentralized wastewater treatment concepts is not only a question of investment costs (expert from group B, *Annex 3*). More attributes can be found in *Figure 9*.

Nevertheless, concerns especially on management issues (controls, service quality, fee collection, asset management) and potentially excessive costs of operation & maintenance are explicitly emphasized as listed in *Figure 9*. How the decentralized solutions are financed and how the funds are allocated were the main remarks of real estate developer and authority experts. The assumption of the study - in agreement with Chinese experts – is that the Chinese Government acts as the customer of decentralized applications by taking over ownership and responsibility for investments and operation. It is therefore assumed, that funds can be allocated to decentralized applications to cover investment and operation expenses instead of funding conventional sanitation including sewer system.

Figure 9: Arguments from expert groups on decentralized wastewater concepts

	Positive attitude, if	Negative attitude, if
Technical	+ technology reliable [group A] + technology easily upgradeable [group D] + technology is suitable to a regions' economical situation [group D] + control systems reliable [group C] + remote control installed [group D]	- technical solution is too complicated [group E] - little standardization possible [group C] - distribution of technology cannot be completed rationally [group D]

	Positive attitude, if	Negative attitude, if
Economic	+ economically reasonable solution [group A] + paying mechanisms of fees clear [group B] + savings on sewer systems possible [group C]	- life-cycle-cost thinking not increasing [group D] - system too expensive [group A] - financing responsibilities unclear [group B]

	Positive attitude, if	Negative attitude, if
Social / environmental	+ installation constraint from government (political pressure) [group A] + management level for operation and maintenance high [group A] + professional service team available [group C] + local governments see added value [group D] + politics is the driving force [group D] + political responsibilities are clearer [group B] + water quality can be ensured [group B] + show cases prove viability [group A]	- control management not worked out properly [group D] - responsibility for operation & maintenance is missing [group A] - professional staff for operation & maintenance is missing [group B] - treated sewage is used directly in households (hygienically / psychological aspects) [group B] - Chinese living conditions not considered sufficiently [group A] - hygienic concerns not eliminated [group C]

3.2.3 Quantitative and qualitative water availability in China

Water scarcity is presented as the relationship between water availability and human population, in other words water availability per capita per year. The most widely used measure is the *Falkenmark water stress indicator* (FALKENMARK, 1992). Falkenmark proposed 1.700m^3 of renewable water resources per capita per year as the minimal threshold for not suffering water stress. When water supply falls below 1.000m^3 a country experiences water scarcity, and below 500m^3 absolute scarcities.

China faces severe water shortages. The shortages are first of all a quantitative problem, i.e. at prevailing prices there is not enough water. Secondly, this naturally brings forward difficulties in maintaining sufficient water quality. Additionally, polluted raw water in China can be observed especially in fast growing industry cities. Quantitative water availability has been judged by the experts as a more relevant driver for water recycling than qualitative water availability (expert from group C, *Annex 3*). To say that experts from water scarce regions are much more sensitized for reclamation initiatives than experts from regions without water shortage. However, only limited water reclamation operations have been implemented to date. A large potential to face both kind of shortages to have an additional water resource would be the reuse of water from conventional treatment plants, whereof only a very small part (less than 1%) of treated wastewater is reused up to date (expert from group A, *Annex 3*).

As the 11th FYP (30% reuse of treated wastewater) heavily promotes effluent reuse all experts admit that now – as new business opportunities open up – experts noted an increased awareness in the water market. Especially sensitive areas such as tourist resorts or natural heritages are pushed forward in the debate of reusing water. Newspapers underline the importance with daily water stories and enterprises proactively interact with governmental departments. The show case for integrated water management including an extend reuse concept in the Olympic park in Beijing has been mentioned in nearly every interview. And as show cases are important in China to promote a business the water scarcest city Tianjin started a remarkable amount of initiatives in reusing treated wastewater (expert from group A, *Annex 3*).

Major concerns of reusing treated wastewater are psychological barriers and hygienic security wherefore strong government surveillance is demanded. In the Olympic show case a reliable and cost effective eutrophication control for the artificial lake involving both natural attenuation capacities (wetlands, bank filtrations) and technological measures (membrane treatment, specific adsorption, optimized process parameters) will be organized (ERNST, 2005). Without exception experts only support water reuse applications that have a control system in place.

As enthusiastic these examples appear the financing question remains unanswered. Current reuse water prices do not reflect full cost recovery as hardly operation costs can be covered by the fees. The driver behind such initiatives is the government that encourages the real estate developers to install new environmental friendly technologies (expert from group C, *Annex 3*). Prices of reclaimed water are rather low (30% to 50% lower than fresh water) and often stable compared with fresh water prices: 1.5 CNY/m3 in Shanghai and only 1 CNY/m3 in Beijing for recycled grey water.

3.2.4 Key statements on decentralized sanitation

Chinese experts confirm that the wastewater market could absorb decentralized wastewater concepts if the questions on funding of the system, operation and pollution control are solved. Quantitative water availability is seen as a main correlation factor for the installation of decentralized systems.

3.3 Conclusion: Sanitation system

Due to poor sanitation in China with its extensive environmental consequences the Government is initiating large investments in wastewater treatment. The most effective allocation of funds, the water scarcity and increasing problems with sludge accumulation are main reasons considering decentralized wastewater concepts as an alternative to successful conventional systems. As a consequence it is essential finding a technology that answers problems of water scarce areas and the sludge issue at costs that are even underbidding the benchmark of conventional installations. In addition, decentralized applications only form a market potential if public hygiene can be ensured and control frameworks are installed.

4 Membrane technology in decentralized application

Optimized investment allocation in the wastewater business, limited water resource availability and increasing sludge accumulation have been outlined in chapter 3 as three main arguments envisaging decentralized wastewater treatment in China's cities. To meet these challenges and to finally estimate a market potential this chapter focuses on the economic and environmental interesting membrane technology suitable for on-site application. Membrane technology is regarded by technicians and scientists as an economically interesting key technology for closing the hydrologic cycle and resource recovery in the centralized and especially in decentralized wastewater treatment market (DOHMANN, 2002). Chinese experts as well privilege this hype technology but strongly concern about the high costs. Even tough many other technologies are valuable alternatives the focus of this study is put on membrane technology exclusively.

The questions of this chapter are about the performances and potentials of a membrane based on-site wastewater application regarding water reuse and sludge avoidance and how much large-scale production could help lower investment costs. In a first step membrane technology in general including its development potential is analyzed. Second, the specification of such a membrane based wastewater treatment plant called TEDE, short word for *technological desire,* is given including cost indications and experts' appraisal. Third, saving potential for TEDE in large-scale production is examined.

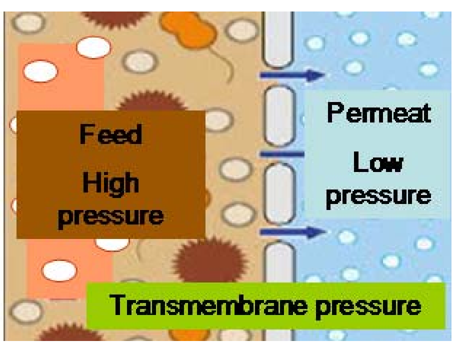
4.1 Membrane technology in general and in China

Membrane applications have been successfully used for processing seawater and water purification and recently similar applications have been adopted for municipal wastewater treatment. The use of membrane technology in the context of limited water availability and potential sludge reduction is explained in this sub-chapter. Furthermore, challenges of the membrane market with its potential for development are described as well as the status of membrane technology in China.

4.1.1 The role of membrane technology in municipal wastewater treatment

Some basic understanding of membrane technology is provided before describing its advantages and disadvantages. Material separation by means of membranes is a physical separation process with the advantage that the separated materials are not chemically or biologically modified. Depending on the separation goal different membrane processes are available. In municipal wastewater treatment microfiltration MF and ultrafiltration UF are used where bacteria, germs and particles are held back completely and most viruses as well. MF/UF in combination with activated sludge process is called membrane bioreactor process MBR where micro organisms are mainly responsible for the treatment efficiency as they decompose and turn wastewater pollutants into biomass. In conventional wastewater treatment biological treatment steps are followed by the three processes sedimentation, filtration and disinfection. These three treatment steps can be replaced through submerged membranes that extract sufficient clean permeate (SIEGRIST, 2004). This permeate can be reused as non-potable water for domestic purposes.

Figure 10: Schematized membrane filtration



Membranes for MF/UF processes are made out of economic interesting, porous polymeric materials (SIEGRIST, 2004). As shown in *Figure 10*, a substance mixture called *feed* is separated by a semi permeable membrane. The part which passes through the membrane almost unhindered is called *permeate*. The driving force of the separation process is the pressure difference between the feed (*overpressure*) and permeate (*depression*) side, the so-called *transmembrane pressure*. The flow through the membrane can be measured and is defined as the volumetric flow rate per unit surface area [L/(m^2*h)]. Currently average flows around 30 [L/(m^2*h)] can be achieved. Of decisive importance for the economic efficiency flows up to 60 [L/(m^2*h)] or more are intended to be achieved.

A membrane module is an assemblage of membrane fibres with a high packing density. For MBR processes spaces saving capillary- or plate-membranes are installed. Additionally, the reactor volume as well can be economized: Sludge concentration in conventional sedimentation processes is limited and therefore large sedimentation basins are required. Since sedimentation is redundant in MF/UF processes higher sludge concentration is possible where larger micro organism spectra can be cultivated that can guarantee a wide and firm decomposition of organic material. Swiss experts are convinced from the sludge reduction potential of MBR and different practical experiences proof this fact. Quantitative details have not been further examined.

Additionally, high treatment quality of MBR systems has been proven according to experts' statements. In operation COD and NH_4–N could be reduced by over 95%. The fact that membrane technology sets one of the highest treatment standards in wastewater treatment makes further discussions about treatment quality comparisons redundant for this study. Besides the high cleaning efficiency space reduction up to 70% compared with conventional biology treatment basins can be achieved with MF/UF in MBR processes.

4.1.2 Challenges on membrane technology

Though the future of membrane based applications in the wastewater business looks bright, there are some difficulties of membranes in operation. The relatively high energy consumption for the aeration of the MBR and for the permeate evacuation is an important challenge. Conventional elimination of pollutants consumes around 0,3 to 0,5 kWh/m^3. Membrane processes in comparison need 1 to 2 kWh/m^3. Flux rates are intended to increase in order to face the energy challenge.

High investment and operating costs of microfiltration due to relatively high MF system prices and with five to eight years the short life time of membranes are another challenge. Membrane costs have already dropped more than 80% since the 1990s. According to experts MF membrane module costs already started to decrease because of increased competition, better system design, and lower manufacturing costs. Further cost reductions are expected during the next years. MBR operation and maintenance costs are difficult to predict as experiences from the field show largely varying cost figures. Improvements in materials and modules, higher permeability, and longer membrane lifetimes would be required to achieve economic advantages.

4.1.3 Membrane technology in China

Membrane technology in China is known for sea water desalination and for process water treatment in industry plants. Among Chinese experts membrane technology is seen as promising technology in the context of effluent reuse. But locally produced membranes are still criticized not delivering comparable treatment qualities as foreign membranes. In practical application the preference is given to internationally produced membrane modules. A national research team is currently analyzing all aspects of membrane technology in order to give national advises for further political technology recommendations. A Chinese wastewater expert admits that *membrane technology is not (yet) compulsory, but as regulations regarding water quality become increasingly stronger the technology can be easier implemented.*

4.1.4 Key statements on membrane technology in general

Membrane technology for wastewater treatment is interesting for China regarding treatment quality with potential for effluent reuse and the low sludge production quantity. The technology can become even more promising for China if investment costs and the relatively high energy demand could be equalized by standardization and performance improvements of the membranes.

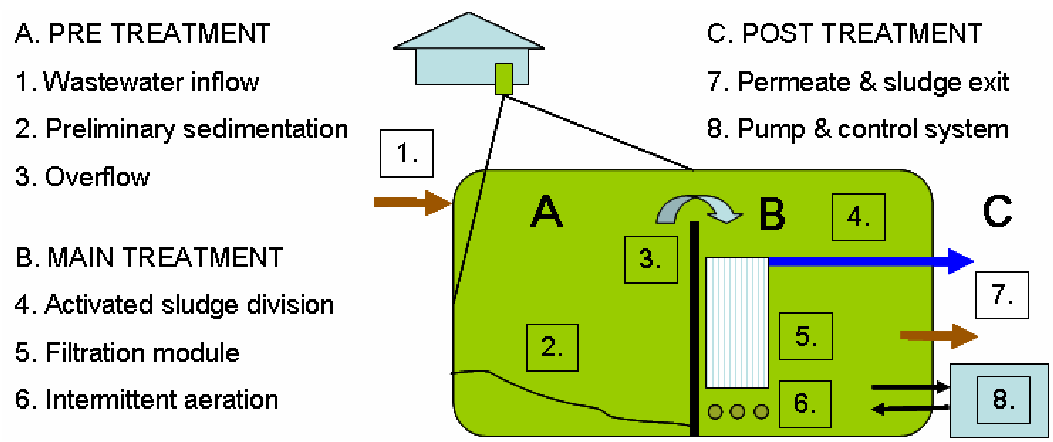
4.2 TEDE concept

Membrane technology with its modularity is applicable for centralized and decentralized use. This sub-chapter describes how membrane technology can be utilized in decentralized systems. For the sake of simplicity this wastewater treatment system for an application of 300 residents is called TEDE, short word for *technological desire*. Before calculating the market potential of TEDE in China (see chapter 5) a reference is made to the Swiss system regarding costs in the next section of this chapter. In addition, the opinion of Chinese experts on TEDE's market implementation is analyzed.

4.2.1 Technical, operative and organisational specification of TEDE

Different TEDE prototypes are available in the market for on-site MBR wastewater treatment of 4 up to 500 residents, whereof specification elements from different supplier companies are taken over for this study. The technical specification TEDE is split up into the processes pre-, main- and post-treatment as shown in *Figure 11*.

Figure 11: Fact Sheet III – Specification of the on-site wastewater treatment system



A Pre-treatment process

The average urban water consumption in China is 204 [L/(P*d)] (NBS I, 2006) and due to more fibered nutrition the composition of the wastewater is slightly different to Swiss wastewater ingredients (expert from group E, *Annex 3*). For further calculations in this report the Chinese average water consumption is used as the wastewater amount and for the sake of simplicity European composition values are applied. Thus, daily raw effluent of 300 residents of around 61 m^3 is flowing from down pipe for wastewater transportation through a sieve into the first smell proof polyethylene, steel or concrete tank. It serves to separate coarse matter and to store wastewater and sludge temporarily (DOHMANN, 2006). Mechanically separated primary sludge remains in the tank.

B Main treatment process

The liquid phase from pre-treatment processes is pumped into the second tank where biological wastewater treatment and phase separation precedes using immersed membrane modules. The biology is aerated in order to ensure micro organism growth and nitrification. Smelly air is conducted through a tube out of the tank. A suction pump withdraws permeate trough the module with 120 m^2 membrane surface out of the activated sludge solution. Daily feed from 300 residents is considered as uniformly distributed so that total volume of both tanks installed in the cellar is equal to daily wastewater discharged (61 m^3 = 4 * 5 * 3 meters) (expert from group E, *Annex 3*).

C Post-treatment process

Permeate is evacuated intermittently from activated sludge solution as membranes need to be backwashed regularly in order to avoid blockage. As mentioned above the solid- and germfree permeate can be either reused or discharged into the rainwater piping network. For this study a simple rainwater piping network has been taken into account for further calculations. The assemblies and switchboard are located outside the tanks. Remote controls can ensure functionality checks of one to multiple TEDE's in operation.

Besides technical specification organisational and institutional arrangements are necessary. With alternative concepts planning, operation, surveillance and administration is different than in conventional wastewater treatment. The planning phase for a TEDE implementation is not further defined in this study. The cost elements of operation and maintenance processes from TEDE in operation are categorized by the three elements: materials including *energy, chemicals* and disposal costs, then expenses on *labour* including surveillance service, and *maintenance* costs. For this study operation factors like stand rental or building insurance are not included. A discussion on control frameworks, financing of alternative concepts and integrative administration are given in chapter 6.

4.2.2 Cost elements of TEDE

Investments, operation and maintenance costs from Swiss centralized sanitation are compared with costs from a TEDE application in this sub-chapter. Swiss sanitation data are taken from the Eawag project *Costs of Swiss Sewage Disposal* (MAURER, 2006).

Figure 12: Annual investment costs TEDE and centralized sanitation

			TEDE		Central	
Investment element			[CHF/capita/year]	Share of total	[CHF/capita/year]	Share of total
Tank	depreciation [y]	50	26	5.4%	0	0.0%
Interests tank	*tax rate*	*3%*	*24*	*5.0%*	*0*	*0.0%*
Installation	depreciation [y]	8	47	9.8%	0	0.0%
Interests installation	*tax rate*	*3%*	*7*	*1.4%*	*0*	*0.0%*
Membran & control panel	depreciation [y]	8	262	54.8%	0	0.0%
Interests membrane and panel	*tax rate*	*3%*	*37*	*7.7%*	*0*	*0.0%*
House connection pipe	depreciation [y]	0	18	3.7%	35	9.8%
Interests house connection pipe	*tax rate*	*3%*	*17*	*3.5%*	*33*	*9.3%*
Sewer	depreciation [y]	80	16	3.3%	83	23.1%
Interests sewer	*tax rate*	*3%*	*26*	*5.5%*	*136*	*38.0%*
Treatment plant	depreciation [y]	80	0	0.0%	45	12.5%
Interests treatment plant	*tax rate*	*3%*	*0*	*0.0%*	*26*	*7.4%*
TOTAL costs			**478**	**100.0%**	**359**	**100.0%**
Total costs in CNY/capita/year			**3'036**			
Total costs in CNY/capita/year @ PPP			**453**			

Investment costs (see Figure 12)

The main investment cost elements of TEDE are the tank, membrane modules, control panel, installation costs, and a simple rainwater discharge pipe. Starting the calculation from a bid of a Swiss TEDE application for four persons, the cost elements are linearly extrapolated to 300 persons. Specific costs per capita are assumed to behave linear, hence, no economies of scale effects for increasing capita units are considered. This has the effect that TEDE investment costs tend to be overestimated. With the calculation according to the cost comparison method the costs for TEDE are 478 CHF/capita/year which is 33% more expensive than the average costs for centralized Swiss sanitation system of 359 CHF/capita/year. Over 60% of the TEDE costs accrue from the membrane module and the control panel. Installation costs in relation to the total investment costs are high due to elevated labour costs of specialist installing TEDE.

Figure 13: Annual O&M costs TEDE and centralized sanitation

	TEDE		Central	
Operation costs	[CHF/capita/year]	Share of total	[CHF/capita/year]	Share of total
Energy & chemicals	14	6.4%	0	0.0%
Labour costs	110	50.4%	0	0.0%
Maintenance	94	43.2%	0	0.0%
Sewer operation	0	0.0%	28	30.6%
Treatment plant operation	0	0.0%	63	69.4%
TOTAL costs	**217**	**100.0%**	**91**	**100.0%**
Total costs in CNY/capita/year	**1'379**			
Total costs in CNY/capita/year @ PPP	**206**			

Operation and maintenance costs

Energy, chemicals, labour costs for TEDE service, and maintenance are considered to be operation and maintenance expense factors. Due to lacking data and little operation experience only little details on O&M for TEDE can be given. In average, it is assumed for a TEDE application for 300 residents that around one man hour per day is required to ensure controls, membrane cleaning and any kind of repairs. The person responsible for the TEDE application does not necessarily need to go on-site for checks as remote control instruments are installed. This labour expense figure is a best guess derived from experts' statements. The figure linearly extrapolated for 300 people not considering any economies of scale tends to be overestimated. As maintenance and upkeep expenses of the TEDE application, 2.5% of the initial investment costs are included in the maintenance cost position. Daily energy consumption of the TEDE operation lies between (61m3 * 0,7 – 1,5 kWh/m3) = 42 to 90 kWh (HUBER, 2006). Comparing annual

O&M costs of Swiss centralized wastewater system with TEDE costs attracts the attention that costs for TEDE are more than twice times higher due to extended labour costs (see *Figure 13*).

Total costs

With 696 CHF/capita/year total annual costs of the non standardized TEDE prototype are 55% higher to than the average costs for the centralized Swiss sanitation system mainly due to elevated operation costs (see *Figure 14*). Not considered in the calculation are ecological advantages and cost savings of reducing the drinking water supply if treated water is reused. With this cost structure a theoretical market potential of TEDE would be marginal.

Figure 14: Total annual costs TEDE and centralized sanitation

	TEDE		Central	
	[CHF/capita/year]	Share of total	[CHF/capita/year]	Share of total
Investment costs	368	52.9%	163	36.2%
Interests on investment costs	*110*	*15.8%*	*196*	*43.6%*
Operation costs	217	31.2%	91	20.2%
TOTAL costs	**696**	**100.0%**	**450**	**100.0%**
Total costs in CNY/capita/year	**4'416**			
Total costs in CNY/capita/year @ PPP	**659**			

4.2.3 Opinion of Chinese experts on TEDE

The TEDE concept including its cost calculations described in the sub-chapter above tends to be a sophisticated top class product for a country not having any sanitation system. But despite financing difficulties, advanced foreign technologies and management experience are badly needed in China due to the environmental difficulties the country is faced with (U.S. DEPARTMENT of COMMERCE, 2005). To estimate the market potential in a later stage of this document the opinion of Chinese experts on TEDE regarding technical, operational and organisational aspects is important to know as only local people decide about implementing a new product.

TEDE specification – technical and economic comments

Except some remarks addressing the foolproofness with frequent breakdowns and the durability of the membranes the TEDE concept presented to the experts has hardly been challenged regarding technical aspects. For experts from the real estate developer group the economical viability of TEDE has been mentioned to be the most important criterion. System suppliers, the academic group and authorities as well define the economics as important elements but with strong environmental reasons their willingness to pay for decentralized solutions would strongly increase. To build up more trust in such a system, experts want to see show cases including exact investment cost calculations.

TEDE specification – operational comments

The TEDE installation and operation has been largely challenged by all experts mainly with following arguments: Too high operation and maintenance costs, lack of skilled people for operation, and responsibilities of service undefined. For system supplier distributing and installing TEDE to atomized locations among the country provides difficulties in terms of logistics and the availability of skilled plumbers. As an answer to these challenges well-known system suppliers started building up a wide-spread distribution and service network to be closer to the *customer*. To admit, that in relation to the other costs elevated Swiss labour costs distort the picture. In China for example, a plumber wage is 30 to 50 CNY/day, which is 32 to 53 CHF PPP/day – still much lower than a Swiss plumber wage, with the effect that TEDE operation costs tend to be overestimated.

TEDE specification – organisational comments

System supplier and the academic group reminded to think of control frameworks to ensure hygienic security. First, even if the funding of TEDE will be done by the government as assumed in chapter 3.2.2 Chinese experts have doubts that without controls the installations are done properly. Second, Chinese experts aim for centrally organized controls of the TEDE operation.

4.2.4 Key statement on TEDE concept

TEDE as a membrane based wastewater treatment plant for 300 residents is technically feasible and from an operating and controlling position viable. Due to elevated investment costs of the hype membrane technology and little operation and control standards costs are rather high compared with conventional wastewater systems. Besides the cost argument Chinese experts mention that for rolling out the TEDE application in Chinese cites a reliable technology, a comprehensive distribution and service network and a centralized control framework are required. Thus, the two main challenges are to decrease the costs of the membrane module and finding viable solutions for the operation and control of this decentralized application.

4.3 Large-scale production

The main hurdle of TEDE is the elevated costs in comparison with conventional sanitation. Lacking standardization and limited large-scale production of a TEDE application for 300 residents are the reasons for not having realized economies of scale. A first question of the sub-chapter is at what quantities which cost savings of TEDE through large-scale production can be achieved. A reference to the Swiss sanitation system regarding suitability in the wastewater market is made. In the second sub-chapter, concepts that help reducing operation and maintenance costs are examined.

4.3.1 TEDE investment cost development

Chinese experts commented the three TEDE investment cost elements *tank, membrane modules, and control panel* on potential savings through large-scale production. The figures received from all groups of experts (see *Annex 3*) were congruent even if the information from system suppliers generally were around 5% higher than from academic experts. Through standardization processes a maximum of 10% cost reduction for the tank is assumed. Experts admit that for annual quantities larger than 1.000 pieces for both membrane modules and control panel a potential cost reduction of 30% is estimated due to standardization, buying power in materials procurement, efficient large-scale production due to larger production facilities, and better manufacturing methods. Exceeding 100.000 quantities even more cost reduction would be feasible through extended production automation.

Investment costs new TEDE

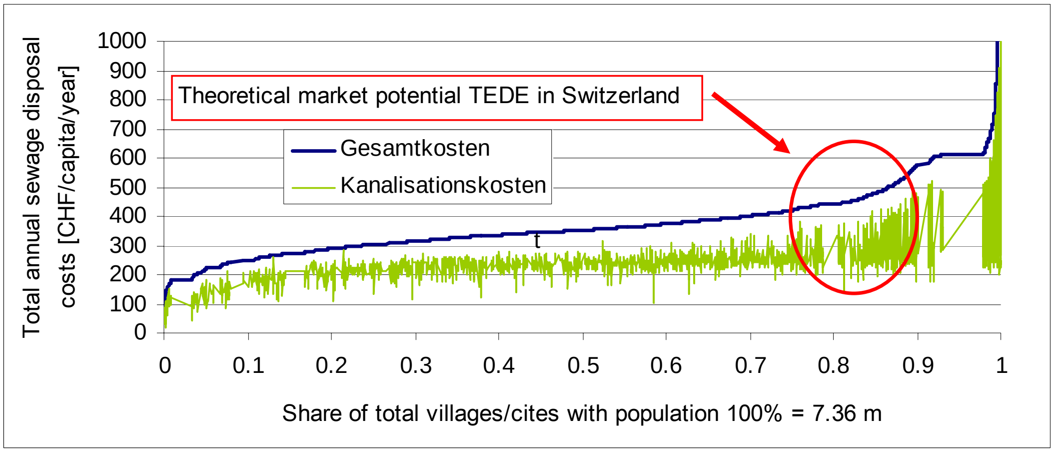
Investment costs of the wishful TEDE product reduce from 478 to 384 CHF/capita/year (see *Figure 15*). That means that through large-scale production total economies of scales of almost 20% can be achieved thanks to the leverage effect of reducing the membrane module. The effects could be even larger if installation costs – distorted by elevated Swiss plumber wages - could be reduced somehow.

Figure 15: Annual investment costs new TEDE and centralized sanitation

			old TEDE	new TEDE	Central
Investment element			[CHF/capita/year]	[CHF/capita/year]	[CHF/capita/year]
Tank	depreciation [y]	50	26	23	0
Interests tank	*tax rate*	*3%*	*24*	22	*0*
Installation	depreciation [y]	8	47	47	0
Interests installation	*tax rate*	*3%*	*7*	7	*0*
Membran & control panel	depreciation [y]	8	262	184	0
Interests membrane and panel	*tax rate*	*3%*	*37*	26	*0*
House connection pipe	depreciation [y]	0	18	18	35
Interests house connection pipe	*tax rate*	*3%*	*17*	17	*33*
Sewer	depreciation [y]	80	16	16	83
Interests sewer	*tax rate*	*3%*	*26*	26	*136*
Treatment plant	depreciation [y]	80	0	0	45
Interests treatment plant	*tax rate*	*3%*	*0*	0	*26*
TOTAL costs			**478**	**384**	**359**
Total costs in CNY/capita/year			**3'036**	**2'436**	
Total costs in CNY/capita/year @ PPP			**453**	**363**	

This cost reduction effect is now applied to the Swiss sanitation system to get an idea what effects such cost reduction theoretically could have. As sanitation costs for the Swiss villages and cities follow a standardized normal distribution a theoretical market potential for TEDE is calculated. Thus, 24% of all villages with sanitation costs higher than 384 CHF/capita/year would be better off installing TEDE than replacing its centralized sanitation system. The sensitivities of this data have not been defined, but the visual observation shows in *Figure 16* that a certain statistical insecurity should be included for further calculations.

Figure 16: Distribution of Swiss centralized sanitation costs



Total costs new TEDE

Operation costs have not qualitatively been challenged for potential savings. Thus, total costs were influenced only by the investment reductions. Total cost reduction is from 696 to 601 CHF/capita/year (see *Figure 17*). As above, the reference calculation of a theoretical Swiss market potential including all cost elements would create a lock-in effect for still 12% of all Swiss villages and cites.

Figure 17: Total annual costs new TEDE and centralized sanitation

	old TEDE	new TEDE	Central
	[CHF/capita/year]	[CHF/capita/year]	[CHF/capita/year]
Investment costs	368	287	163
Interests on investment costs	*110*	*97*	*196*
Operation costs	217	217	91
TOTAL costs	**696**	**601**	**450**
Total costs in CNY/capita/year	**4'416**	**3'815**	
Total costs in CNY/capita/year @ PPP	**659**	**569**	

4.3.2 TEDE organisational concepts

In this study, operation and maintenance costs are kept unchanged for the wishful large-scale product TEDE as data from field reports hardly are available and as techniques for efficient operation and controls are not mature. Thus, a reduction is so far not quantifiable. As a sugges-tion to anyhow reduce costs of operation and control tasks could be a centralized monitoring system where online measurements from multiple area-wide decentralized TEDE applications are collected and screened. Apparently, such a system is available in the market according to an international system supplier, but further details have not been examined.

4.3.3 Key statements on large-scale production

TEDE investment costs including installation could be reduced by 20% at annual quantities of more than 1.000 pieces due to large-scale production in China. Applying this wishful product to the Swiss sanitation market a theoretical market share between 12% and 24% could be captured with this decentralized application. Now, it is of interest to know if and where such market share could be achieved in China.

4.4 Conclusion: Technology

For water reuse membrane technology in China is seen as promising technology in providing an additional water resource and being an alternative to large sludge investments. The membrane based wastewater treatment system TEDE offers 20% economies of scale through large-scale production exceeding 1.000 quantities annually and could therefore create an economically interesting *lock-in* effect whereby decentralized outrivals centralized concepts. For example in Swiss sanitation could this wishful product create a theoretical market share between 12% and 24%. From a wastewater market point of view factors like distribution of the new product, operation and maintenance services, and system controls are important besides the economies of the product for successfully rolling out this system.

5 *Market assessment for TEDE in China*

The construction of outdated and new wastewater treatment plants and piping systems in China creates a large market demand for relevant technology and equipment. In Swiss sanitation system it could be more economical for 12-24% of the villages and cities to allocate investment funds on the wishful large-scale produced membrane based decentralized applications instead of building up a conventional centralized system. Applying this share on the Chinese wastewater market interesting business opportunities for suppliers of decentralized systems could open up as China is about extending its sanitation system with over 90 bn CNY (see Chapter 3.1.3) during the next years. Hence, it is interesting to investigate if, and how much of this share could be applied in China. System suppliers in China are keen to know where and how big the market potential of on-site wastewater applications is. Authorities as well are interested knowing the market potential as they want to optimally allocate governmental funds.

The questions of this chapter are about where and under what circumstances a market for decentralized application in China can be defined, how the market segment for TEDE (specification see chapter 4.2) can be quantified. Following the methodology from chapter 2.1 the first sub-chapter analyzes the segmentation attributes *geographic, demographic and the buying motive*. Finally, the market potential of TEDE is quantified in the second sub-chapter and valuated by sensitivities.

5.1 Market segmentation

Total wastewater market in China includes all urban and rural regions and can be divided into the contaminator segments *industry, agriculture and municipal*. This study focuses on the sub-segment *urban municipal wastewater*. Segmentation is rather complex as the major Chinese cities are extremely inhomogeneous regarding water distribution, buying power and real estate development. However, this sub-chapter describes the geographical and demographic segmentation of the sub-segment *urban municipal wastewater*, as well as the segmentation by buying motive is defined.

5.1.1 Geographical segmentation

A conclusion from chapter 3 is that mainly water scarce regions have an urgent need for alternative sanitation systems with additional water reuse functionality. A definition of water scarcity by the Falkenmark indicator is pointed out in the same chapter. Combining the Falkenmark indicator with the water resource availability data from the statistical yearbook of China gives information about Chinese provinces suffering of water stress or scarcity.

The calculation according to Falkenmark outlines 10 provinces, 3 municipalities, and 1 autonomous region to be water scarce regions (for details see *Annex 6*). These 14 regions are located in the most densely populated North and Southeast of China where around 280 million people life in 321 major cities (see *Annex 6* and *Figure 18*). Extremely arid areas of Northwest China where precipitation is less than 400mm per year, do not appear in the list as the water resource per person still is higher than for example in Shanghai municipality with over 1.000mm of annual precipitation.

Figure 18: China map with water scarce provinces marked

For reason of data availability, seasonal water scarcity and selective tourist and environmentally sensitive areas commented in chapter 3.2.2 are not taken into account for further calculations with the effect that for example Chongqing municipality bearing a large market potential is excluded as well.

5.1.2 *Demographic segmentation*

The scale and speed of urban renewal and expansion in China is unprecedented. According to the WORLD BANK (2001) the urban population of China will increase from currently 557 to 670 million people by end of the year 2015 and the urban building stock is expected to double again in the next 15 years. With the average floor space in urban areas of 29 m^2/capita, new annual floors space of around 965 million m^2 (CER SUPPLEMENT, 2007) will be built in the water scarce areas, whereof 17% is due to urban growth and 83% is due to replacement investments (for details see *Annex 7*). 50 high-rise buildings with 300 residents each has been defined in chapter 3.2.2 as a decentralized area in China. Splitting up the floor space according to this around 112.000 new high-rise buildings will be built each year.

Market cultivation is possible through expansion of the market and/or through market crowding out. The easiest way rolling out the TEDE product is the installation into new buildings as the ex post assembly into existing buildings often causes unpredictable technical difficulties. To avoid additional complexity, market potential calculation of this study underlies the assumption that TEDE is exclusively installed in new buildings.

5.1.3 *Segmentation by buying motive*

The study underlies the assumption that TEDE is funded by the Chinese Government through reallocation of funds that are foreseen for investments into conventional sanitation. Depending on the political impact and especially on the cities buying power Chinese Local Governments have different motivation in investing funds to the decentralized wastewater business. A radical, a fair, and a moderate buying motive could be derived of statements from Chinese experts.

Radical buying motive – green behaviour

Chinese experts have stated an increased willingness to pay for TEDE application in sensitive areas. In the cities Beijing, Shenzhen, Henan and Qingdao regulations for installing water recycling applications in new apartment buildings are already established. A positive willingness to pay and established regulations are indeed two criteria that could support a large TEDE market potential. For the *radical buying motive* it is assumed that political compulsory regulations for the installation of TEDE are imposed and therefore an implementation rate of 100% is derived.

Fair buying motive – western behaviour

With some reservations regarding sewer systems Chinese experts are keen to rely on experiences from industrialized countries. Switzerland is giving the reference concept in this study. Due to economical reasons the large-scale product TEDE could cause a lock-in effect for 12 to 24% of Swiss villages and cities. Following the Swiss reference system it is assumed for China that in the *fair buying motive* 12 to 24% of the market *new municipal buildings in major Chinese water scarce cities* can be worked.

Moderate buying motive – no risk behaviour

New concepts and technologies often receive rave reviews. Nevertheless, reliable economic data to calculate a realistic buying motive were not accessible for China. A *best guess* calculation helped in approaching this *moderate buying motive*. The initial comparison shows that the Chinese sanitation system only requires 17 to 34% of the replacement costs of the conventional Swiss sanitation system (see chapter 3.1.3). Reducing the *Swiss* lock-in effect of 12 to 24% from the *fair buying motive* by this 17 to 34% proportion, there is 2% to 8% (=12%*17% respectively 24%*34%) *Chinese* lock-in effect remaining.

5.1.4 Key statements on market overview

The main characteristic of North East and South East of China are water scarcity plus tremendous densely populated cities. As these cities are growing fast the conditions for a decentralized wastewater treatment market are given. Through geographic and demographic segmentation arguments the market segment for decentralized wastewater applications' *new municipal buildings in major Chinese water scarce cities* is defined and quantified. The buying motive of Chinese Local Governments points out three different scenarios for the quantification of TEDE sales in the defined market segment.

5.2 TEDE market quantification

New municipal buildings in major water scarce cites of China can be defined as the target segment for TEDE. To answer the main question of this study about TEDE's market potential this sub-chapter quantifies the target market segment and discusses its sensitivities.

5.2.1 Market potential of TEDE

After the definition of the market segments its quantification is the next task for the final market potential calculation. Two kind of market potentials are calculated in this sub-chapter. The first calculation shows the market potential of TEDE at investment costs. The second computation points out the market potential of TEDE at investment and operation costs whereby an integrated picture of public expenses is expressed. The market potential is indicated as a monetary cipher and also as a quantitative volumetric number in order to differentiate the needs of the two different stakeholder groups *system supplier* and *authorities*.

Market potential of the large-scale product TEDE

With the cost comparison method annualized investment costs of the large-scale product TEDE including fixed costs, interests and the rainwater discharge infrastructure component make up 363 CNY/capita/year @ PPP (384 CHF/capita/year) as calculated in chapter 4.3. According to the cost comparison method evaluation, in this segment a recurring annual market potential for TEDE's life time is calculated. Depending on the buying motive scenario the Chinese national budget would be charged by 244 to 12.217 million CNY @ PPP per year. In other words, system supplier could take advantage of that potential sales volume. *Figure 19* gives the overview over the data.

Figure 19: Potential calculation of TEDE product

Buying motive	TEDE share	Annual new TEDE buildings	TEDE fixed costs		TEDE market volume product		Treatment capacity for
		[number]	[CHF/capita/year]	[CNY/capita/year @ PPP]	[m CHF / year]	[m CNY / year @ PPP]	[m people]
Radikal	100%	112'080	384	363	12'901	12'217	33.62
Fair - high	24%	26'899	384	363	3'096	2'932	8.07
Fair - low	12%	13'450	384	363	1'548	1'466	4.03
Moderate - high	8%	8'966	384	363	1'032	977	2.69
Moderate - low	2%	2'242	384	363	258	244	0.67

Market potential of the large-scale product TEDE and its variable costs

The second market calculation is done with annualized product costs of the TEDE product and its variable costs of 569 CNY/capita/year @ PPP (601 CHF/capita/year, see chapter 4.3) in order to reflect total annual expenses of the Chinese national budget. These *real* annual expenses would be 383 to 19.136 million CNY @ PPP per year. Again in other words, the system suppliers could annually offer investments and services for 383 million CNY @ PPP or more. See *Figure 20* for more details.

Figure 20: Potential calculation of TEDE product and its variable costs

Buying motive	TEDE share	Annual new TEDE buildings	TEDE fixed & variable costs		TEDE market volume product		Treatment capacity for
		[number]	[CHF/capita/year]	[CNY/capita/year @ PPP]	[m CHF / year]	[m CNY / year @ PPP]	[m people]
Radikal	100%	112'080	601	569	20'207	19'136	33.62
Fair - high	24%	26'899	601	569	4'850	4'593	8.07
Fair - low	12%	13'450	601	569	2'425	2'296	4.03
Moderate - high	8%	8'966	601	569	1'617	1'531	2.69
Moderate - low	2%	2'242	601	569	404	383	0.67

5.2.2 Sensitivities of TEDE's market potential

The market potential calculation is an attempt to show system suppliers theoretical quantitative achievements in the Chinese wastewater market with a wishful large-scale product and support authorities in judging investments in decentralized wastewater applications. Quantitative as much as qualitative arguments underlie uncertainties as this study is based on many assumptions. Therefore, the sensitivities of technical, economic, environmental and social assumptions are qualitatively assessed. The aim of this assessment is to make qualitative statements on the market potential development (see *Figure 21*). To quantitatively evaluate the market potential outcome of the three buying motives further research would be required.

Technical assumptions

Technical changes of the TEDE specification, lower economies of scale effects in the large-scale production, and variances in operation and maintenance costs would strongly influence the market potential of the market segment with ‘fair and moderate buying motive.

Economic assumptions

The Chinese National Government is assumed to fund decentralized applications. In case, other funding initiatives should be considered would have a strong effect on the market potential estimation of the market segment by radical buying motive.

Environmental assumptions

Regions with quantitative water scarcity are assumed to build up the market potential. The inclusion of areas with seasonal or qualitative scarcity could enlarge the market segment for all buying motives.

Social assumptions

The extension of the TEDE implementation on existing buildings by regulation would have a positive market potential effect for the radical buying motive. For reasons of little political support and self motivation in installing TEDE hardly no market potential effect is expected for the market segment with moderate buying motive.

Figure 21: Sensitivities influencing the market potential of the three buying motives

Impact of…	Radical buying motive	Fair buying motive	Moderate buying motive
…technical assumption	L	H	H
… economic assumption	H	M	L
… environmental assumptions	H	M	L
…social assumption	H	M	L

H means high, M means medium, L means low impact on market potential

5.2.3 Key statement on TEDE market quantification

The market potential for the large-scale product TEDE and its variable costs is quantified according to three different market segmentation scenarios. The radical scenario assumes that through political regulation the whole market segment *new municipal buildings in major Chinese water scarce cities* is accessible. Whereby, the moderate scenario assumes that this market segment only can be accessed if costs of TEDE are lower than for conventional systems. Depending on the segmentation scenario *radical, fair or moderate buying motive* a market potential of more than 244 million CNY @ PPP per year can be proposed. Variations in the environmental and social assumptions of this study could have a positive effect on market potential calculation as variation of the technical and economic assumptions could have a negative impact.

5.3 Conclusion: Market

The market segments for decentralized membrane based wastewater treatment applications are new municipal buildings in major Chinese water scarce cities. Depending on the buying motive the market for offering this technical application varies between 244 and 12.217 million CNY @ PPP per year. System supplier offering besides the product a service and control solutions could face a market between 383 and 19.136 CNY @ PPP per year.

6 Conclusions

The goal of this study was to find out more about market potential in China for the membrane based wastewater systems in decentralized application of urban wastewater treatment. To approach the goal four questions on centralized and decentralized sanitation, about membrane technology and large-scale production, and market specialities have been explored. The research questions can be segmented according to environmental, social, technical and economic aspects. Conclusions on these aspects are summarized and discussed in this chapter by simultaneously answering the research questions.

6.1 Conclusions on environmental / social aspects

In industrialized countries conventional wastewater treatment technology has become sophisticated at predictable investment and maintenance costs and enjoys public acceptance. This largely successful concept has shown its limits in some developing and transition countries like China, especially in fast-growing cities with limited water resources. Chinese experts consider the high water requirement for wastewater transport in areas suffering quantitative water scarcity and the increasing sludge accumulation as the main limitation factors of this conventional sanitation system. Decentralized sanitation with its modular character is considered to be an effective way in facing rapid urban growth and with its potential to locally reuse water an additional water resource can be tapped.

With a wastewater treatment rate of 22% sanitation in China is poor and leads to extensive environmental consequences. The protection of public health and the conservation of water resources as the main goals of a sanitation system are not achieved. Hence, the Chinese Government is initiating large investments in wastewater treatment. Chinese experts admit that the most effective allocation of governmental funds, water scarcity and increasing problems with sludge accumulation are main reasons in China considering decentralized wastewater concepts as an alternative to conventional systems. In this study a decentralized unit is defined to be an apartment building of 300 residents.

Chinese experts further admit that the wastewater market in China can absorb decentralized wastewater concepts if besides the economic viability the questions of responsibility, operation of the applications and pollution control are solved. Regulations and responsibility concepts to compulsory implement decentralized wastewater treatment in water scarce areas are hardly introduced. Additional regulations by Local Governments could speed up in starting a decentralized sanitation era.

6.2 Conclusions on technical aspects

Many technologies could be considered for decentralized wastewater treatment. To answer the water scarcity and the sludge accumulation issue at once membrane technology is seen among international and Chinese experts as a promising technology. Material separation by means of membranes is a physical separation process delivering more efficient treatment qualities than conventional technologies. Additionally, treated water can be reused for non-potable applications. Membrane technology with its modularity is applicable for space-saving decentralized use. Different prototypes are available in the market for wastewater treatment of 4 up to 500 residents, whereof specification elements from different supplier companies are taken over for this study. Means from a technical perspective no additional features need to be specified for the Chinese market.

Answers from Chinese experts confirm that the membrane based wastewater treatment system could theoretically offer 20% economies of scale through large-scale production of more than 1.000 quantities per year. Therefore, an economically interesting effect could be created while decentralized concepts are about outrivaling centralized sanitation systems. Applying this wishful product to the reference concept *Swiss sanitation market* a theoretical market share between 12% and 24% could be captured.

But large-scale production is not yet realized. Again, one reason is the lacking political regulations favouring decentralized systems and therefore system supplier wait building up a production facilities. Another reason is the concerns from authorities and academics about services and controls of systems. They fear that public hygiene cannot be ensured due to the atomized distribution of treatment plants among the country. Reliable solutions regarding this issue are internationally tested in show cases whereby the costs caused are still unsatisfying high.

Additionally, time horizon has not been considered during the product evaluation. The need in China to act is urgent. But even if compulsory regulations for decentralized wastewater treatment by membrane technology would be implemented in China by tomorrow, time required for rolling out a large-scale product starting from a prototype would take one to two years. In order to potentially speed up the roll out of decentralized wastewater treatment applications international system and solution suppliers based in China could principally start building up pilot schemes.

6.3 Conclusions on economic aspects

After qualitative analyzes on water scarcity and quantitative economies of scale calculations three main market segments for this wishful decentralized membrane based wastewater treatment system are derived. The first market segment are new municipal buildings in the 321 major Chinese water scarcest cities *with a buying motive of 100%* due to the assumption that compulsory regulations for the installation of this system are imposed. According to the cost comparison method evaluation, in this segment a recurring annual market potential for the life time of the decentralized wastewater treatment product would exceed 12.000 million Chinese Yuan @ PPP.

Second, following the Swiss reference concept it is assumed for China that *with a buying motive of 12 to 24%* the market *new municipal buildings in major Chinese water scarce cities* can be worked, as Chinese experts are keen to rely on experiences from industrialized countries. Again, according to the cost comparison method evaluation, in this segment a recurring annual market potential for the life time of the decentralized wastewater treatment product could be 1.466 to 2.932 million Chinese Yuan @ PPP.

Third, with a pure economic – and probably most realistic - consideration and without any political regulations, the *buying motive would still be 2 to 8%* leading to an annual recurring market potential of 244 to 977 million Chinese Yuan @ PPP. The market for services as operation and maintenance could additionally reach 139 to 554 million Yuan @ PPP per year for this market segment.

The market potential calculation of this study was an attempt to show system suppliers theoretical quantitative achievements in the Chinese wastewater market with a wishful large-scale product and to support authorities in judging investments in decentralized wastewater applications. From a quantitative as much as qualitative perspective analyzing a theoretical market potential was possible with making a detour to the Swiss sanitation system and with the definition of a bunch of assumptions. Thus, uncertainties like the definition of the buying motives were certainly created. Testing these uncertainties by sensitivity analyzes turned out to be difficult. To quantitatively evaluate the market potential outcome further research would be required.

The study assumes that the Chinese Government acts as the customer of decentralized applications by taking over ownership and responsibility for investments and operation. It would be interesting to further analyze financing and organisational alternatives. As financing alternative, for simultaneously speeding up a possible implementation of decentralized wastewater systems, and to overcome potential gaps of a Local Government's budget, international system and solution supplier could offer financing schemes such as the BOT (build-own-transfer) concepts. In the BOT concept the authorized party is responsible for the financing, design, construction, operation, maintenance, and management of the project during the contracted period.

Annex

Annex 1: Currency conversions according to the World Bank

	local currency units to $ [2003]	PPP: local currency units to international $ [2003]		local currency units to CHF [2007]	PPP: local currency units to international CHF [2003]
Switzerland [CHF]	1.35	1.9		1	1
China [CNY]	8.28	1.8		6.348	0.947
United States [$]	1	1		0.819	0.526

Annex 2: Interview guideline and questionnaire

Background of Research Study

The Water Research Institute EAWAG from Switzerland is internationally famous for its research studies in 'Urban Water Management'. As a 'Water Management' student Adler Corinna is doing a master thesis together with EAWAG. The goal is to find out more about the market potential for decentral wastewater treatment with membrane technology in China.

Information

A membrane based system is a HIGH-TECH PRODUCT for decentral wastewater treatment in houses and high rise buildings (300 people). The cleaned wastewater can be reused for irrigation, flushing and washing. Downside: The costs per person for the membrane based system are still higher than the costs per person for the central infrastructure.

Questions

PART I – Wastewater treatment (WWT) in China

Use of Fact Sheet I - wastewater concepts

A Central WWT concepts

Please give your comment on central WWT

Do you have any practical experiences with central WWT?

Do you know the sewage treatment rate of some Chinese cities?

What are the up- and down-sides of the current system?

Who are the relevant stakeholders?

What are the costs per capita for canalisation / WWTP / operation?

Do you calculate the projects with full cost pricing?

Use of Fact Sheet II - on-site wastewater treatment

B Decentral WWT concepts

Please give your comment on decentral WWT

Do you have any practical experiences with decentral projects (e.g. 300-500 people)?

Do you think decentral concepts have a potential in the "water scarce' future?

C Water recycling

Please give your comment on water recycling / reuse

Do you have any practical experiences with water recycling?

Who are the stakeholders for production / selling / buying?

Can you give some cost examples of recycling water?

PART II – Membrane based decentral WWT system

Use of Fact Sheet III - specification of on-site wastewater treatment system

D Membran technology

What are your practical experiences with membrane technology in WWT?

Can you imagine to install a decentral WWT system according to the fact sheet III?

How much is the costs of membrane technology in WWT? (e.g. CNY/m2)

What will be the further development of the membrane technology?

How do you see the cost development of membrane technology?

How much are the costs for operation and maintenance in infrastructure with membrane technology?

What are the political acceptance / legislation for membrane technology?

What is the willingness to pay for new technologies?

Where can the decentral WWT system be installed?

E Serial production

Do you think serial production of decentral WWT system is possible?

Please indicate the price decrease in % for MEMBRANE from 1.000 to 10.000 to 100.000 pieces?

Please indicate the price decrease in % for CONTROL PANEL from 1.000 to 10.000 to 100.000 pieces?

Please indicate the price decrease in % for TANK from 1.000 to 10.000 to 100.000 pieces?

PART III – Market environment

F Market implementation

What are the requirements to implement / install decentral WWT system?

What is the political / legislative requirement?

How could the operation and maintenance be organized?

How fast could the decentral concept be implemented?

G Market segementation

Where do you see the biggest potential for decentral applications?

H Market hurdles

What difficulties and market hurdles do you see?

What will be the market acceptance of decentral systems?

Acknowledgement

Annex 3: List of experts and specialists

Name	Organization and function	Details	Stakeholder group	Origin
ABEGGLEN Christian	Eawag	Decentralized wastewater treatment & membrane technology	E - Swiss specialist	SWITZERLAND
CAO Jun	Project Manager, Shanghai Machinery Complete Equipment Group Ltd.	Water Equipment & Engineering	D - System Supplier	CHINA Shanghai
CHEN Frank	Group Marketing, Geberit	Wastewater China	E - Swiss specialist	SWITZERLAND
DAEBEL Helge	Private Equity Analyst, SAM Sustainable Asset Management	Water investments	E - Swiss specialist	SWITZERLAND
DAQUN Zhang	Director, Water Industrial Institute Machinery & Electricity Committee of China & General Manager, Tianjin Water Engineering Ltd.	Water engineering & Membrane Technology & water reuse	C - Real estate developer	CHINA Tianjin
FENG Xu Dong	Deputy Chief Engineer, East China Architechtural Design Institute ECADI Ltd.	Building design	C - Real estate developer	CHINA Shanghai
FUTAI Chen	Vice Director, Research & Application Center for Membrane Technology, Tsinghua University	Membrane Technology & applications	A - Academic	CHINA Beijing
HILS Bruno	CEO, Picatech Huber AG	Wastewater treatment & membrane technology	E - Swiss specialist	SWITZERLAND
HUANG Cheng	Vice Chief Engineer, Shanghai Qing Cao Sha Raw Water Engineering Ltd.	Water Equipment & Engineering	D - System Supplier	CHINA Shanghai
JIANG Wenyuan	Retired Water Expert China	Wastewater applications & legislation & Regulations	B - Authorities	CHINA Shanghai
JOSS Adriano	Eawag	Membrane Technology & applications	E - Swiss specialist	SWITZERLAND
KELLER Bruno	Professor, Bauphysik, ETH Zurich	China & real estate	E - Swiss specialist	SWITZERLAND
KINZELBACH Wolfgang	Professor, Institute for Hydromechanics, ETH Zurich	China & water	E - Swiss specialist	SWITZERLAND
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Annex 4: Overview Chinese provinces including information about population

Name	Administrative status	Region definiton	Number of residents	Number of urban residents
			[2005] [m]	[2005] [m]
Beijing	Municipalities	north china	15.4	12.9
Tianjin	Municipalities	north china	10.4	7.8
Hebei	Provinces	north china	68.5	26.0
Shanxi	Provinces	north china	34.0	14.3
Inner Mongolia	autonomous region	north china	24.0	11.3
Liaoning	Provinces	north east china	42.0	24.8
Jilin	Provinces	north east china	27.0	14.3
Heilongjiang	Provinces	north east china	38.0	20.1
Shanghai	Municipalities	south east china	18.0	16.0
Jiangsu	Provinces	south east china	75.0	37.5
Zhejiang	Provinces	south east china	49.0	27.4
Anhui	Provinces	south east china	61.0	22.0
Fujian	Provinces	south east china	35.0	16.5
Jiangxi	Provinces	south east china	43.0	15.9
Shandong	Provinces	north china	92.0	41.4
Henan	Provinces	north china	94.0	29.1
Hubei	Provinces	south east china	57.0	24.5
Hunan	Provinces	south east china	63.0	23.3
Guangdong	Provinces	south east china	92.0	56.1
Guangxi	autonomous region	south west china	47.0	16.0
Hainan	Provinces	south east china	8.0	3.6
Chongqing	Municipalities	south west china	28.0	12.6
Sichuan	Provinces	south west china	82.0	27.1
Guizhou	Provinces	south west china	37.0	10.0
Yunnan	Provinces	south west china	44.0	13.2
Tibet	autonomous region	north west china	2.7	0.7
Shaanxi	Provinces	north china	37.0	13.7
Gansu	Provinces	north west china	26.0	7.8
Qinghai	Provinces	north west china	5.0	2.0
Ningxia	autonomous region	north china	6.0	2.5
Xinjiang	autonomous region	north west china	20.0	7.4
TOTAL			**1281.0**	**557.8**
Hongkong	SAR (special administrative regions)			
Macao	SAR (special administrative regions)			

Annex 5: Treatment capacities per province

	Number of urban residents	Official treatment rate	Efficiency of treatment plants	NEW capacity by year 2010	Total capacity by year 2010	Total capacity per urban capita in year 2010
	[2005] [mln]	[2005]	[2005]	[1.000 CMD]	[1.000 CMD]	[CMD/capita]
Beijing	12.94	53.9%	55.4%	331	3051	0.236
Tianjin	7.80	53.6%	87.3%	766	1696	0.217
Hebei	26.03	49.0%	59.9%	495	2625	0.101
Shanxi	14.28	54.8%	67.3%	324	1244	0.087
Inner Mongolia	11.28	48.9%	48.2%	466	1376	0.122
Liaoning	24.78	45.3%	66.2%	1728	4788	0.193
Jilin	14.31	23.6%	41.1%	1246	2256	0.158
Heilongjiang	20.14	33.5%	57.7%	1821	2681	0.133
Shanghai	16.02	75.1%	94.6%	1008	5438	0.339
Jiangsu	37.50	76.1%	55.0%	2344	6494	0.173
Zhejiang	27.44	53.4%	63.9%	875	3775	0.138
Anhui	21.96	44.9%	45.0%	1344	2754	0.125
Fujian	16.45	46.7%	61.1%	1406	2906	0.177
Jiangxi	15.91	24.2%	35.7%	1044	1534	0.096
Shandong	41.40	51.8%	58.3%	1210	5430	0.131
Henan	29.14	44.6%	71.2%	742	2982	0.102
Hubei	24.51	40.7%	55.2%	625	2555	0.104
Hunan	23.31	38.1%	42.1%	828	1998	0.086
Guangdong	56.12	33.7%	79.7%	3907	9337	0.166
Guangxi	15.98	31.7%	47.8%	906	1486	0.093
Hainan	3.60	52.8%	60.3%	198	578	0.161
Chongqing	12.60	20.8%	43.4%	426	896	0.071
Sichuan	27.06	32.1%	55.7%	2449	4149	0.153
Guizhou	9.99	12.1%	77.3%	320	470	0.047
Yunnan	13.20	59.2%	57.7%	1492	2352	0.178
Tibet	0.73			51	51	0.070
Shaanxi	13.69	22.9%	72.5%	367	727	0.053
Gansu	7.80	34.8%	50.0%	117	627	0.080
Qinghai	1.95	18.5%	70.6%	120	205	0.105
Ningxia	2.52	44.1%	43.9%	153	593	0.235
Xinjiang	7.40	67.9%	51.1%	889	2049	0.277
TOTAL	**557.835**	**45.7%**	**63.6%**	**30000**	**79105**	**0.142**

Annex 6: Key figures of water scarce regions

		Water rescources per capita	Falkenmark indicator	Annual precipitation	Number of urban residents	Number of major cities
		[2005] [m^3/person]		[2005] [mm]	[2005] [m]	[calc]
Beijing	Municipalities	151	absolute scarcity	411	12.94	1
Tianjin	Municipalities	102	absolute scarcity	619	7.80	1
Hebei	Provinces	197	absolute scarcity	390	26.03	26
Shanxi	Provinces	252	absolute scarcity	275	14.28	26
Liaoning	Provinces	896	scarcity	822	24.78	33
Shanghai	Municipalities	138	absolute scarcity	1060	16.02	1
Jiangsu	Provinces	626	scarcity	992	37.50	30
Anhui	Provinces	1178	water stress	1091	21.96	40
Shandong	Provinces	451	absolute scarcity	965	41.40	40
Henan	Provinces	597	scarcity	728	29.14	40
Hubei	Provinces	1640	water stress	1116	24.51	28
Shaanxi	Provinces	1322	water stress	541	13.69	23
Gansu	Provinces	1042	water stress	432	7.80	28
Ningxia	Autonomous region	144	absolute scarcity	75	2.52	5
TOTAL					**280.4**	**321**

Annex 7: New annual floor space for water scarce provinces

	Annual floor space through urbanization	Annual new TEDE buildings through urbanization	Annual floor space through replacement investments	Annual new TEDE buildings through replacements	Annual new TEDE buildings total
	[m m^2]	[number]	[m m^2]	[number]	[number]
Beijing	7	867	37	4'304	5'171
Tianjin	4	523	22	2'595	3'118
Hebei	15	1'745	75	8'661	10'406
Shanxi	8	957	41	4'751	5'709
Liaoning	14	1'661	71	8'245	9'906
Shanghai	9	1'074	46	5'330	6'404
Jiangsu	22	2'513	107	12'478	14'991
Anhui	13	1'472	63	7'307	8'779
Shandong	24	2'775	119	13'775	16'550
Henan	17	1'953	83	9'696	11'649
Hubei	14	1'643	70	8'155	9'798
Shaanxi	8	918	39	4'555	5'473
Gansu	4	523	22	2'595	3'118
Ningxia	1	169	7	838	1'007
Total water scarce areas	**162**	**18'791**	**803**	**93'288**	**112'080**
Total China	**322**	**37'388**	**1'598**	**185'613**	**223'001**

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